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Acid Precipitation and Drinking Water Quality in the Eastern United States

New England Water Works Association, Dedham, MA

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ACID PRECIPITATION AND DRINKING WATER QUALITY IN THE EASTERN UNITED STATES

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16. ABSTRACT

A research project was conducted to provide accurate modern and historical data on drinking water quality and the possible effect of acid precipitation on water samples. Samples of source raw and finished water were collected from more than 270 surface and groundwater supplies in the New England States, New York, New Jersey, Pennsylvania, West Virginia, Virginia, and North Carolina. The samples were analyzed at EPA laboratories. Historical records were obtained dating back to 1886.

Acid rain may dissolve harmful elements from soils and, indirectly, from water supply distribution systems. Because soils can alter the character of acid rain through buffering, causal relationsips are difficult to identify. A helpful approach to this problem is the use of indices of water supply sensitivity and corrosiveness. With these indices, drinking water standards, and reliable chemical data, an assessment of water supply characteristics has been accomplished.

Though solution products of acid rain in water supply sources studied do not exceed EPA Primary Drinking Water Regulations, a large number of tests for aluminum showed levels that could be of concern to patients using kidney dialysis. Because of the present water quality conditions (low alkalinity and pH) observed at numerous water sources, future acid deposition could be expected to have a detrimental effect on water quality. Quantification remains a problem, however.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled lands are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

This study was designed to evaluate the quality of drinking water in the New England, Appalachian, and coastal States. Because acid rain can directly or indirectly dissolve harmful elements such as lead, cadmium, and mercury, it could adversely affect drinking water quality. Extensive data have been obtained through analyses of present water quality and study of historical documents that provide a basis for better understanding the problem.

Francis T. Mayo
Director
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ABSTRACT

A research project was conducted to provide accurate modern and historical data on drinking water quality and the possible effect of acid precipitation on water samples. Samples of source raw and finished water were collected from more than 270 surface and groundwater supplies in the New England States, New York, New Jersey, Pennsylvania, West Virginia, Virginia, and North Carolina. The samples were analyzed at EPA laboratories. Historical records were obtained dating back to 1886.

Acid rain may dissolve harmful elements from soils and, indirectly, from water supply distribution systems. Because soils can alter the character of acid rain through buffering, causal relationsips are difficult to identify. A helpful approach to this problem is the use of indices of water supply sensitivity and corrosiveness. With these indices, drinking water standards, and reliable chemical data, an assessment of water supply characteristics has been accomplished.

Though solution products of acid rain in the water supply sources studied do not exceed EPA Primary Drinking Water Regulations, a large number of tests for aluminum showed levels that could be of concern to patients using kidney dialysis. Because of the present water quality conditions (low alkalinity and pH) observed at numerous water sources, future acid deposition could be expected to have a detrimental effect on water quality. Quantification remains a problem, however.

This report was submitted in fulfillment of Cooperative Agreement CR807808010 by the New England Water Works Association under the sponsorship of the U.S. Environmental Protection Agency. The report covers the period November 1, 1981, to January 31, 1984, and work was completed as of January 31, 1984.

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SECTION 1

INTRODUCTION

Seldom has an environmental phenomonon aroused so much interest as acid precipitation, or as it is popularly known, acid rain. Acid precipitation, according to Cowling's historical review (1), is not a recently discovered phenomenon. Nevertheless, concern has grown in recent years, and the U.S. Environmental Protection Agency (EPA) has funded research to gain information on the ecological effects of acid precipitation on forests, crops, and fish.

This study was undertaken to learn about the quality of drinking water in areas receiving acid precipitation. The states included in this study were Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Pennsylvania, West Virginia, Virginia, and North Carolina.

This report contains information on present water quality and on the past quality of water, as indicated by records at certain water utilities and the Lawrence Experiment Station in Massachusetts. Historical data were used to search for water quality changes with time. Present data were evaluated against the EPA's standards for drinking water to learn whether maximum contaminant levels for metals have been exceeded. Present water quality data were also used to calculate indices that are used to evaluate tendencies of waters to dissolve or to deposit scale. The extent to which raw water quality may have been influenced in past years by above-normal rainfall, drought, and stream flow was not evaluated, as this was beyond the scope of the study.

SECTION 2

CONCLUSIONS

1. In raw waters that were sampled, acid precipitation has not caused lead, cadmium and mercury to be present concentrations related to health concerns. The Environmental Protection Agency's health-related Maximum Contaminant Levels for lead, cadmium and mercury were exceeded very seldom in raw waters sampled in New England and the Adirondack Mountain region of New York in 1981 and 1982.

2. The pH of raw waters from New England and New York's Adirondack Mountain region sampled in 1981 and 1982 was frequently outside of the acceptable range for pH (6.5 to 8.5) as specified in the EPA's Secondary Maximum Contaminant Levels (SMCL's), which may be applied at the option of each state. Generally the pH was lower than 6.5 when the SMCL was not met.

3. The pH of drinking water can be adjusted upward as necessary to meet the SMCL.

4. Indices of water quality based on calcium carbonate solubility indicated that most of the waters sampled in the study would tend to dissolve $CaCO_3$ rather than precipitate $CaCO_3$. Most of the waters sampled in 1981 and 1982 would be expected to be corrosive based on Ryznar's Stability Index.

5. Many of the waters sampled had more than 0.1 mg/L aluminum, where the maximum amount recommended by the American National Standards Institute for dialysis water is 0.01 mg/L. (The EPA has not set a standard for aluminum in drinking water.)

6. Ground waters from sand aquifers had some of the lowest pH and alkalinity values observed in this study.

7. The concentration of copper in water allowed to stand in household plumbing lines overnight before being sampled was equal to the SMCL or exceeded the SMCL (1 mg/L) in about 40 percent of the samples. Water standing in service lines overnight equalled or exceeded the SMCL for copper in about 20 percent of the samples.

8. The 0.05 mg/L Maximum Contaminant Level for lead in drinking water was exceeded in 7 of 129 household water samples. The MCL violations occurred mainly in samples that had remained overnight in household plumbing.

9. Trends of alkalinity vs. time were obtained for 34 water sources in Massachusetts. Of this number 18 had a declining slope that was statistically different from a zero slope (no change with time), and 2 had a slope with a statistically significant (0.05 level) increase. Alkalinity and pH of Scituate Reservoir in Rhode Island have both declined over the past forty years. Slopes of both were statistically different from zero at the 0.05 level. With respect to Scituate Reservoir, this is consistent with an acid precipitation cause and effect hypothesis.

10. No direct relationship was found between the occurrence of acid precipitation and the decline in alkalinity in 19 raw water sources, nor was any relationship found between the occurrence of acid precipitation and the unstable and potentially corrosive nature of these sources. Nevertheless, given the limited buffering capacity in these supplies, the historical downward trend in alkalinity and the low pH of the rainfall in the study area, the potentially detrimental effects of acid precipitation should not be discounted. More study should be undertaken on this issue.

SECTION 3

RECOMMENDATIONS

1. The historical data obtained in this project should be studied further. This study included only a portion of the historical data in the archives of the Lawrence Experiment Station. Further work should be done to evaluate the additional information available in order to learn about trends in water quality parameters.

2. Additional study of alkalinity is needed, from late 1940's to early 1960's, a time when changes in alkalinity are the most noticeable. Influences of weather and hydrology should be evaluated.

3. On the basis of the water quality indices related to $CaCO_3$ and the copper content of household water samples, implementation of corrosion control activities in many of the communities from which water samples were obtained, would be appropriate.

4. More household samples should be obtained in areas surveyed having the lower raw water pH values.

SECTION 4

REVIEW OF LITERATURE

In this section, acid precipitation is discussed briefly, and water quality standards and indices are explained. Health effects of lead and aluminum in water are reviewed.

ACID PRECIPITATION

The events that cause acid precipitation are complex, and they can occur at locations far from the place where the precipitation falls. Sources of acid precipitation include oxides of nitrogen and sulfur dioxide, resulting from combustion of fuels (2), and gases such as sulfur dioxide and hydrogen sulfide (3) from volcanoes and other natural sources.

Acid precipitation can impact the ecosystem in a variety of ways. A review of the effects of acid precipitation by Glass, Glass, and Rennie (4) indicated that agricultural crops may receive direct effects of precipitation on foliage surfaces or indirect effects because of changes brought about in the soil. They also stated that the quality of surface waters can change, with reductions in pH and alkalinity occurring. N. R. Glass et al. (5) stated that soils and bedrock geology influence the degree to which lakes or streams may be susceptible to acidification. Haines (6) reviewed surface water chemistry and discussed the effects of acidification on non-fish aquatic biota and fish populations. Driscoll et al. (7) studied the effect of aluminum on fish in acidified waters.

WATER QUALITY STANDARDS

After water samples were analyzed in this study the water quality characteristics were compared to values set as standards for drinking water quality and to indices that have been used to obtain estimates of whether a water might cause scaling or attack calcium carbonate films in water mains and plumbing.

The EPA's National Interim Primary Drinking Water Regulations (NIPDWR) (8) set maximum contaminant levels for ten inorganic chemicals, including lead (0.05 mg/L) and cadmium (0.010 mg/L). The Primary Regulations are to be enforced throughout the USA by the States or EPA. Evidence of the need for a maximum contaminant level (MCL) for lead was confirmed in a study by Craun and McCabe (9) in which they reported that when household water-lead content in the sample during the day exceeded 100 ug/liter and the data were controlled for proximity to traffic density, a significantly increased frequency of blood-lead concentrations in excess of 35 ug/dL was found.

Because cadmium or lead or both might appear in drinking water as a result of corrosion, the results of lead and cadmium analyses were compared to the maximum contaminant levels (MCL's) to learn to what extent the MCL's were exceeded in the samples collected in this study.

The EPA published secondary maximum contaminant levels (SMCL's) for pH, copper, zinc, iron, and several other water quality characteristics in the Federal Register in 1979 (10). SMCL's are not mandatory on a national basis, but they may be enforced by a state if it chooses to do so. The SMCL for pH is given as a range of 6.5 to 8.5, and pH is to be within that range. The SMCL for copper is 1 mg/L, for zinc it is 5 mg/L, and for iron the SMCL is 0.3 mg/L. "These levels represent reasonable goals for drinking water quality," EPA stated in the Federal Register.

A substance not regulated by EPA, but which can cause health problems, is aluminum. Relatively small amounts of aluminum can be hazardous to persons who depend upon kidney dialysis. An outbreak of dialysis encephalopathy (dialysis dementia) has been reported in Minneapolis (11) where the aluminum content of the dialysate was 200 ug/L, and this pathology was also observed in Great Britain (12) in cases where aluminum in the water supply ranged from 300 to 1200 ug/L. The American National Standards Institute (13) has established a limit of 0.01 mg/L for aluminum in dialysates. This is not an enforceable drinking water quality standard.

QUALITY INDICES

Over the years, water chemists and researchers have attempted to develop water quality indices to indicate the corrosive tendency of water. According to Singley, "the literature of the water utility industry is full of attempts to develop a corrosion index." (14) Water quality indices based on calcium carbonate solubility are shown in Table 1.

The Langelier Index (LI), proposed in 1936 (15), was intended to indicate the tendency of water to dissolve or precipitate calcium carbonate on water main walls. The index was intended to be an indication of the directional tendency but not of capacity to precipitate or dissolve calcium carbonate. Positive LI values indicate a tendency to precipitate calcium carbonate. A zero value indicates saturation, with neither precipitation nor dissolution of calcium carbonate. A negative LI value indicates a tendency to dissolve solid calcium carbonate. Use of the LI was discussed and suggested in the EPA's August 27, 1980 ammendments to the NIPDWR, which stated that the LI should be calculated to determine corrosivity (16).

Ryznar's Stability Index (SI) was proposed in 1944 (17). Ryznar used the pH_s as calculated in the Langelier Index, but the Stability Index scale was related to field observations of scaling and of corrosion of water mains (Fig. 1). Thus the SI perhaps more closely approaches the concept of a corrosion index. Among the waters from which data were used to prepare Ryznar's graph of SI vs. corrosion and scaling were soft, low total dissolved solids (TDS) waters of the Mokelumne supply for the East Bay Municipal

TABLE 1. FORMULAE FOR INDICES OF WATER QUALITY RELATED TO CORROSION

Langelier Index (LI)

$LI = pH - pH_s$* where (1)
pH is the actual pH value of the water
pH_s is the pH of the water at saturation with calcium carbonate

Ryznar or Stability Index (SI)

$SI = 2pH_2 - pH$ (2)
pH_s is the pH of the water at saturation with calcium carbonate
pH is the actual pH

Aggressive Index (AI)

$AI = pH + \log(AH)$ where (3)
A is the alkalinity in mg/L as $CaCO_3$
H is the calcium hardness as $CaCO_3$ in mg/L

---

* See Federal Register Wednesday-August 27, 1980, Part IV, Environmental Protection Agency, Interim Primary Drinking Water Regulations, P57357, for the complete formula for pH_s and a short formula for pH_s using Tables for temperature and total filtrable residue.

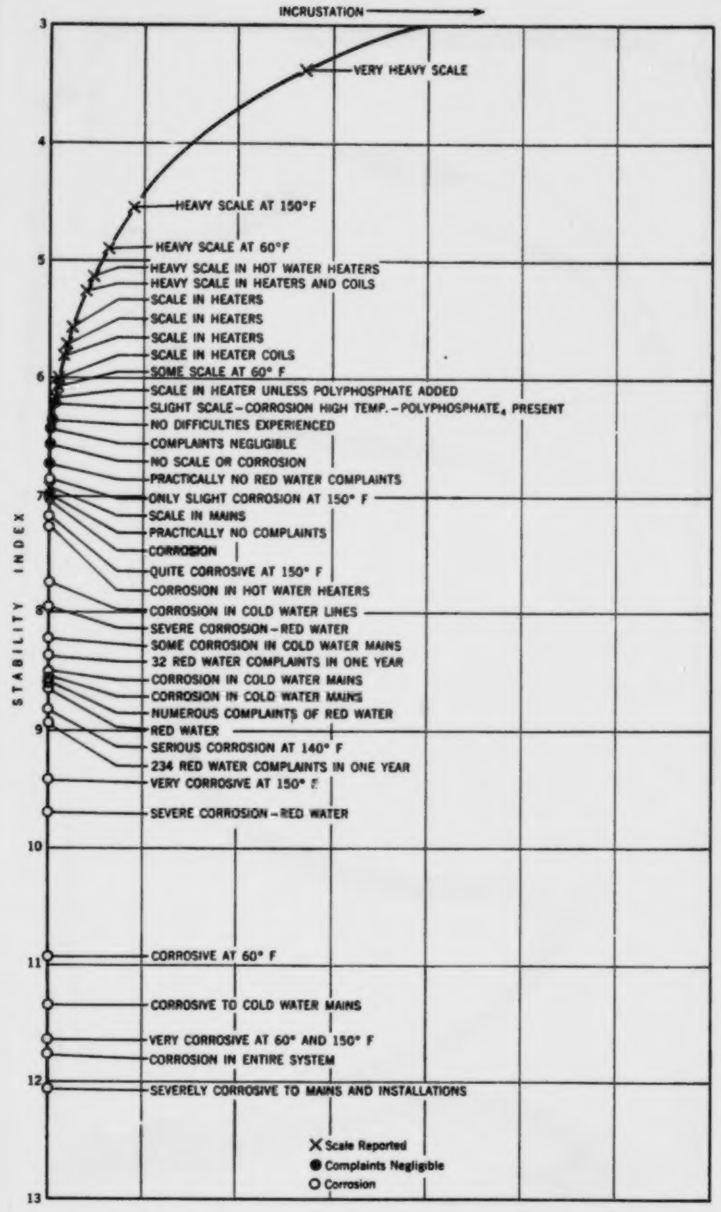

Figure 1. Field Results of Survey of Corrosion and Scaling
Compared with Ryznar Stability Index
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Utility District (California), the Hetch Hetchy Reservoir of San Francisco, and the Catskill supply of New York City. The above-mentioned mountain waters are similar in quality to many of the waters analyzed in this study, i.e., soft, with low TDS rather than hard with moderate to high TDS.

Use of Ryznar's Stability Index to characterize waters in this study should be helpful, within limits. First, the observations regarding corrosion were related to corrosion of ferrous metals, rather than lead pipes. Second, the SI does not take into account any use of corrosion inhibitors, because SI calculation is based only on calcium carbonate chemistry. With these limitations taken into consideration, the SI is used in this report.

The formula for the Aggressive Index (AI) was proposed in 1975 in the Foreword of AWWA C400-75, AWWA Standard for Asbestos-Cement Pressure Pipe, 4 in. through 24 in., for Water and Other Liquids (18). The revised standard, C400-77 (19) using the same formula discussed criteria for transporting water through asbestos-cement (A-C) pipe in terms of aggressiveness (concerning the behavior of water, aggressive and corrosive are similar terms). For nonaggressive water (AI $\geq$ 12.0) either Type I or Type II A-C pipe could be used. For moderately aggressive water (AI = 10.0 to 11.9) use Type II A-C pipe. For highly aggressive water (AI $\leq$ 10.0) serviceability of the pipe must be established. Later, use of the Aggressive Index to ".... determine the corrosivity of the water ...." was discussed by EPA on p. 57346 of the Federal Register (16) when the final rule on the corrosion regulation was published. The Aggressive Index is merely an abbreviated and approximate form of the Langelier Index.

Another index based on calcium carbonate saturation is the Calcite Saturation Index (CSI). This index (shown in Table 2) has been developed (20, 21) and used (22) to describe the ability of bodies of water to assimilate acid precipitation but it also can be useful in evaluating the condition of watersheds. Although developed primarily for surface waters it can also apply to groundwaters. For example, a watershed or aquifer having a raw water with a CSI value about 4-5 would be even more susceptible to change by acid deposition (i.e., incapable of much further buffering), whereas ones with CSI <1 would have capacity for buffering acid precipitation for years to come.

The indices mentioned here, as well as others related to corrosion, should be used with caution. Singley (14) stated, "Use of any corrosion index should be correlated with field test results in order to determine its applicability to a given water. All of those currently available have considerable quality specificity."

TABLE 2. CALCITE SATURATION INDEX

Calcite Saturation Index (CSI)

$CSI = \log K - \log (Ca^{2+}) - \log HCO_3^- - pH$

where $\log K = 2.582 - 0.024T\,^{\circ}C$

and Ca^{2+} and HCO_3^- in moles/L

and HCO_3^- = total alkalinity as $CaCO_3$ for pH <9.3

and HCO_3^- is less than H^+

CSI Values	CSI Classification
<1	Terrain is most stable and not susceptible to change
1-2	Possibly susceptible to change
2-3	Probably susceptible to change
3-4	Susceptible to change
4-5	Highly susceptible to change.

SECTION 5

METHODS AND PROCEDURES

FIELD ACTIVITIES

Staff

The first step in this study was appointment of the field staff, one for each state. These persons were selected for their experience, familiarity with the water supplies and terrain of their states, and who had the respect of the water supply operators and state authorities. This was important because the field staff would interact directly with water utility personnel by visiting water treatment plants, collecting water samples, and searching for historical data.

Before the sampling began, the Round 1 and Round 2 field staff members were assembled in the offices of the New England Water Works Association, where they were given instructions on:

1. Procedures for sampling
2. The use of the pH meter
3. Recording of data on EPA forms
4. Packing and shipping sample containers to EPA/Cincinnati

This instruction period was conducted by Michael Schock, Chemist, EPA, DWRD, MERL, Cincinnati, Ohio.

Following this instructional meeting, a step-by-step procedure sheet was developed for use by the field staff members. Next, a second meeting of the field staff was held in the EPA Laboratory in Lexington, Massachusetts, where John J. Collins of Providence, the Rhode Island field engineer (chemist) gave a hands-on demonstration of the proper techniques for sampling, determining pH, recording data, and packing and shipping samples.

Instruction for Round 3 field staff was conducted by Floyd Taylor. Giving common instructions to all field staff members was done so that each person would use the same procedures in carrying out the work.

Sampling Program

The field study was divided into three phases: Round 1 in 1981, Round 2 in 1982, and Round 3 in 1982-1983. States included in Rounds 1 and 2 were Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut, and New York (Adirondack Mountain region). States included in Round 3 sampling were Massachusetts (Martha's Vineyard), New Jersey, Pennslvania, West Virginia, Virginia, and North Carolina. Names and locations of Round 1, 2 and 3 communities and sources are given in Appendix I.

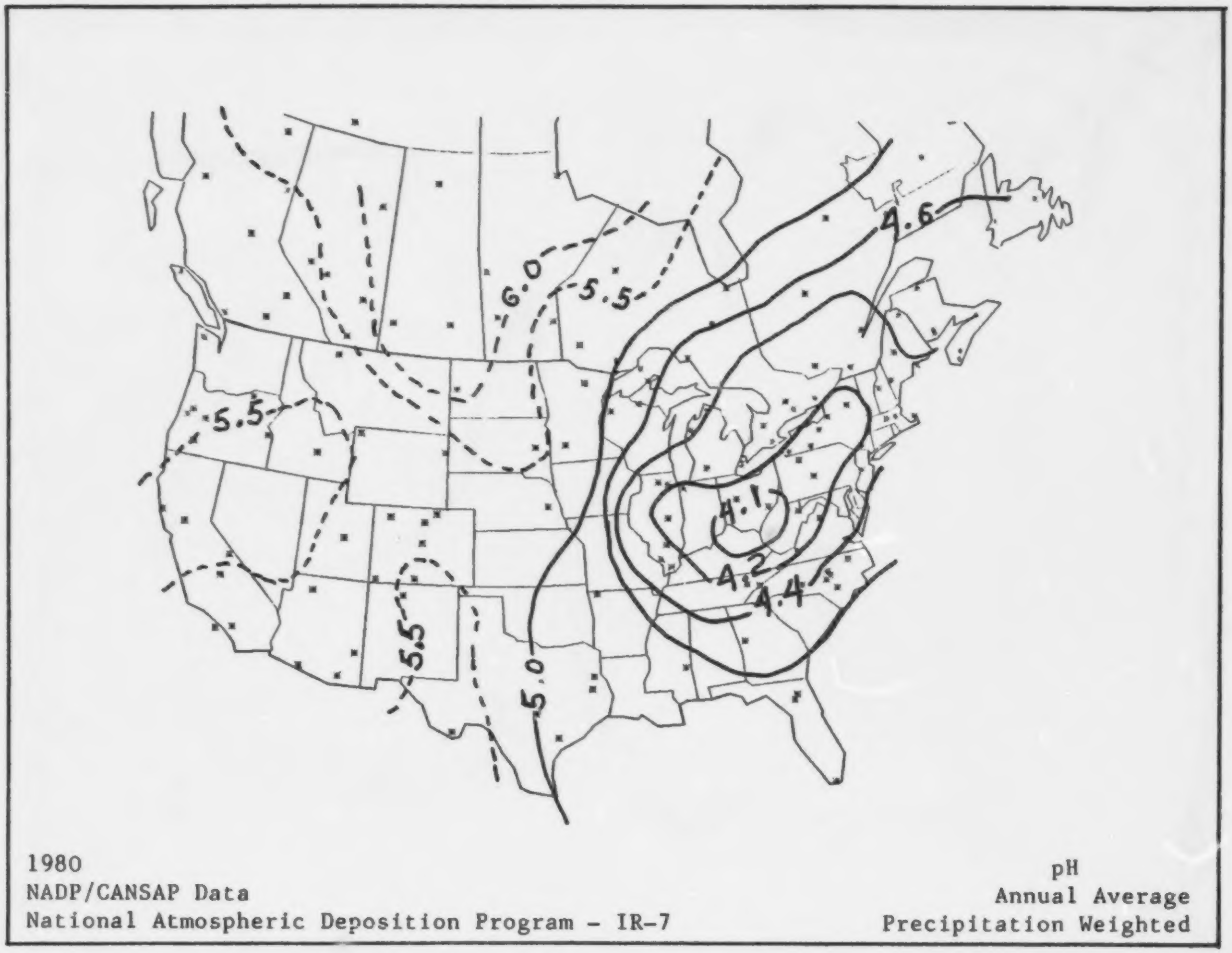
Figure 2 shows the geographical pattern of rainfall pH in the United States. The states included in this study are among those having low pH rainfall and, in some locations, bedrock geology and soil conditions that result in poorly buffered surface waters or ground waters or both.

In the Round 1 sampling, surface waters were studied wherever possible because studies of aquatic effects of acid precipitation had generally been related to surface waters. Samples were taken from well supplies only where it was deemed desirable. Generally this occurred in areas where only ground water was used for drinking water. Because of financial constraints, approximately 7 percent of the total surface supplies in each of the states were to be sampled. In New York, only the Adirondack Region was included, because this part of the state was considered most susceptible to damage by acid precipitation. EPA data on the number of community water supplies and the number of sampling sites selected in the several states are shown in Table 3.

The original proposal was to sample 7 percent of the surface water supplies, 44 percent of the population, and an estimated 25 percent of the miles of public water supply piping in the study area. Although the populations served by the selected supplies dwell largely in urban areas, the supplies themselves are mainly in rural areas. New England communities generally have protected water supply sources by forbidding recreational use and by promoting land acquisition by water purveyors to further insure unpolluted supplies. Few streams are used for water supply. Only four of the surface supplies numbered above are streams. Disinfection is the only treatment for most of these water supplies.

Following the determination of the number of sites to be sampled in each state, the geographical distribution of the sampling sites was established. Preliminary locations were suggested by the individual field staff members after consultation with the respective state health departments and other organizations.

Final decisions were made by consultation between EPA and the NEWWA. Besides the suggestions of the field staff members, geographical distribution factors were also important in the final selection. In Maine, selection favored high elevations in the western and northwestern areas where the precipitation is influenced more by the St. Lawrence Valley weather as opposed to the coastal weather in the southern and eastern parts of the state. In the Adirondack Mountain region, there is a large park of some 6 million acres; the selected sites were distributed rather equally across the northern, central, and southern sections of the park. Not all of the sites selected were public supplies. The number of such sites varied from state to state.



1980
NADP/CANSAP Data
National Atmospheric Deposition Program - IR-7

pH
Annual Average
Precipitation Weighted

Figure 2. Average Annual Rainfall pH, 1980 (Prepared by J. H. Gibson and C. V. Baker; Reproduced by permission of the National Atmospheric Deposition Program)

TABLE 3. FREQUENCY OF DISTRIBUTION OF SITE SELECTION

State	Community Total (No.)[a]	Water Supplies Surface (No.)[a]	No. Sites Selected Total [b]	Well	(3)-(4)= % % of Total
(1)	(2)	(3)	(4)	(5)	(6)
Connecticut	827	413	23	2	5.57%
Maine	384	192	14	2	7.29
Massachusetts	700	350	25	-	7.14
New Hampshire	707	353	29	4	8.2%
Rhode Island	113	56	7	1	12.5
Vermont	358	179	13	-	7.26
New York (Adirondack)	300[c]	150	12	1[d]	8.0
Total	3380	1693	123	10	7.26%

(a) EPA data
(b) Selected by joint action of EPA (DWRD) and NEWWA
(c) Estimated
(d) Groundwater supply for resort area

The sampling program for Round 2 was planned after the Round 1 collection program in the summer of 1981 was completed. In the spring of 1982 a limited number of sites, specifically those that had shown low pH values in the 1981 tests, were resampled for Round 2. Water samples were also collected from some households in Round 2.

In addition to the above sampling, groundwater supplies were sampled in the general vicinity of the resampled sites. The distribution and number of sites sampled in this second round are listed in Table 4.

Round 3 of the sampling was designed to explore the chemical composition of 67 groundwater supplies, geographically distributed in the Appalachian area of the states of Pennsylvania, West Virginia, Virginia, and North Carolina and in the Pine Barrens and Coastal area of New Jersey (a sand aquifer). The list of these supplies is shown in the Appendix. In addition supplies on Martha's Vineyard, Massachusetts were included in the third sampling program because the water source is a sand aquifer.

Prior to the start of the field studies, the water supply official in each community to be visited was contacted and advised of the study and its official purpose. The need for local cooperation was explained and requested and a date was set for the sampling visit. Excellent cooperation was received from the water utility personnel.

Sample Collection

The planned procedure for the field site visits called for: collecting samples of both raw and treated water; determining water temperature; determining pH by glass electrode and electronic pH meter; recording of data; and preparing sample containers (Cubitainers® and bottles) for shipment to and analysis by EPA-DWRD, Cincinnati. In most of these site visits, the field staff members were able to carry out the procedures at the plant site, especially where the plants had well-equipped laboratories. In some instances, however, it was necessary to transport the samples back to a motel, or to the investigator's home where the equipment could be set up properly. In some cases, obtaining samples of the raw water was not possible, for reasons such as lack of a spigot on the raw water pump. Other problems of similar nature were encountered.

Before the sampling survey actually began in each state, each member of the field staff ran through the sampling and pH testing procedures and assembled the equipment and supplies for easy transport and quick handling at each sampling location. It was found that on-site time could be reduced if all sample bottles, accompanying record forms, and shipping boxes were prepared on the night before the sampling site visit.

At each sampling point, three samples were taken, two 1-quart polyethylene Cubitainers® were rinsed with sample water and then filled. In the 1-quart container used to collect an acidified water sample, 1.5 mL of concentrated nitric acid was added from an unmarked glass ampule obtained from either Poly Research Corporation (Deer Park, New Jersey) or G. Frederick Smith Chemical Company (Columbus, Ohio). The lot number of the acid was noted on the EPA-9 forms. Both containers were sealed with

TABLE 4. SAMPLING SITES IN ROUND 2

State	Resampled Sites	New Groundwater Sites
Connecticut	4	3
Maine	5	4
Massachusetts	14	17
New Hampshire	10	25
Rhode Island	4	11
Vermont	3	5
New York	5	9
Total:	45	74

These sites are listed in Appendix I and are shown on the State maps.

polyethylene inserts washed with sample water, and the containers were closed with plastic screw caps with foam liners. Additional samples were taken in 125 mL high density linear polyethylene bottles, or 125 mL PVC bottles. In later sampling rounds, 250 mL PVC bottles were substituted. These sample bottles were filled to overflowing and closed with Poly-Seal® screw caps, having conical polyethylene liners to eliminate an airspace in the bottles when completely filled. All samples were then mailed First Class to the EPA Laboratory in Cincinnati, Ohio, for analysis.

In the first round of field visits, samples were collected from free-flowing taps at the plants. The stepwise procedure used for sampling and reporting analysis was as follows:

- In order to minimize air mixture, a sample was carefully collected for pH determination at the site or at a nearby point. A standard EPA-9 form was completed to identify each sample.
- The temperature in °C of the sample was determined by glass thermometer.
- A series of 5 pH measurements was carefully made and recorded, and these were averaged using the geometric mean of pH.
- Samples of raw and finished water were taken and acidified for the metals portion. These were sent to the EPA, DWRD, in Cincinnati, Ohio.
- The EPA Laboratory made determinations for 25 water quality parameters, recording the data on standard EPA-6 forms, which were sent to the NEWWA office.
- Copies of the EPA-6 forms were sent to the field staff who sent one copy to each of the participating water purveyors.

In the second sampling round, where repeat sampling was done, the procedure was the same but there were two additional variations.

(1) Three special samples were collected early in the morning from selected houses on the distribution system. The purpose of this sampling was to ascertain the effect of the low pH water on the household piping. The first sample was collected immediately on opening the tap; this was water stored overnight in the house plumbing. The second was taken a minute or so later, which was water from the service line, and the third after an additional five minutes of continuous discharge, which was water from the town distribution system. All three samples were acidified by the householder for shipment to EPA-DWRD, Cincinnati. These samples were collected from the homeowners by a representative of the local water utility or by a representative of the district office of the state health department. The three sample series give information on the quality of water stored in household

plumbing and service lines as well as on quality in the distribution system.

(2) During the second sampling round, certain precautions were taken on groundwater samples, whereby a special tap was employed to avoid entrapment of air in the sample bottles. In many cases the groundwater sources were not readily accessible and in several instances, the assistance of district health office personnel was utilized to locate and reach these places.

In the third round of sampling (in the states of New Jersey, Pennsylvania, West Virginia, Virginia and North Carolina), only groundwaters were sampled following the procedures established previously.

Analysis of pH

Analysis of pH was performed in the field, according to the method of Schock, Mueller and Buelow (23). Samples were analyzed in a closed 40 mL vial. The samples were stirred with a magnetic stirrer. Sargent-Welch Model 5000 portable pH meters were used, with combination electrodes. For each water tested, five of the 40 mL vials were filled and capped to prevent contact with air before the analysis began. Each pH electrode was fitted with a rubber stopper to minimize contact of the sample with the atmosphere during the analysis.

Two-point standardizations were used for all pH measurements. At each site before pH analysis, the meter was first standardized with pH 6.86 buffer, then with either pH 4.01 buffer or pH 9.18 buffer, depending upon the anticipated pH for the water sampled. If the water turned out to have a pH on the opposite side of pH 6.86 than the second buffer used, the pH meter was restandardized with the appropriate second buffer, and the pH was measured again.

Historical Data Collection

Each of the field personnel visited the agencies in his state to compile water quality data pertaining to the selected sites assigned to him. These searches alone contributed a great store of information covering periods of ten to fifty years or more for nearly all of the raw water sources, but availability of historical information was not uniform from state to state.

In addition to these archival data collected from state, district, and local health departments, information was obtained from articles published by health department and university investigators in previous years. In Massachusetts, for example, the records of Lawrence Experiment Station provided an abundance of information. Local historical and plant operating data were reviewed and pertinent information extracted for comparison with data obtained in the current study. The entire data collection effort generated over 100,000 items of information.

The quality of the historical data varied. The Lawrence Experiment Station data were found to be the most useful because of the length of coverage and the strict observance of standard methods for water quality testing that was practiced at that laboratory.

LABORATORY ACTIVITIES AND QUALITY ASSURANCE

The analytical support provided by the Inorganic and Particulate Control Section, Physical and Chemical Contaminant Removal Branch, EPA, DWRD, was in several areas. In addition to the actual chemical analysis of all monitored constituents aside from field-measured pH, the assistance consisted of solution preparation, supply of ultrapure-grade concentrated nitric acid ampules for sample preservation, supply of specialized sample containers and consultation on sampling and pH measurement problems. The quality assurance practices associated with the different analytical and solution preparation phases are summarized below. All quality assurance data presented in this report, including and the results of blind unknown, field duplicates, and quality control samples for the newly-employed potentiometric titration methods for low-level chlorides and alkalinity are tabulated in Appendix II.

Solution Preparation

The EPA Laboratory prepared filling solutions for the combination pH electrodes used in the field, as well as the pH buffers used for calibration.

For the combination electrodes with Thalamid internals, a 3M KCl solution was prepared by dissolving the appropriate amount of Analytical Reagent Grade KCl in deionized water. The solution was then filtered through a 0.4 um Nucleopore® membrane filter. Deionized water was produced by passing distilled water through a Barnstead Nanopure® 4-column deionization system.

For the combination electrodes with Ag-AgCl internals, the filling solution was prepared by refrigerating commercially prepared 4M KCl saturated with AgCl overnight. The supernatant liquid was poured off into containers for use by the field engineers.

Precautions were taken in preparing the filling solution to prevent a junction's clogging from KCl precipitation and to stabilize electrode response at the low sample temperatures anticipated for cold water sampling.

Buffer solutions were also prepared at the EPA Laboratory for distribution to the field engineers. The solutions were prepared by dissolving weighted quantities of Beckman or Altex brand salts in deaerated, CO_2-free deionized water. Buffers of pH 4.00, 6.86 or 7.00, and 9.18 at 25°C were stored in collapsable polyethylene concertina bottles sealed with polyethylene inserts and plastic screw caps and were shipped upon request via First Class mail. Before the pH buffer solutions were sent, they were analyzed with a digital pH meter and glass electrode calibrated with buffer solutions prepared from U.S. National Bureau of Standards salts and stored protected from the atmosphere in glass bottles with CO_2-absorbing tubes in the vent lines. Any buffer solution that did not agree to within 0.02 pH of its theoretical value was rejected and not sent. Tables of buffer pH at different temperatures in increments of 1° C were calculated by linear regressions of data at wider temperature intervals provided by the manufacturers and were sent along with the buffer solutions.

Sample Analysis

All samples were initially received by the DWRD where research chemists, sanitary engineers, and technicians who did not participate in any of the analyses other than pH, alkalinity, and potentiometric chlorides performed the appropriate sample logging, splitting, addition of blind unknowns and submission to the analytical support group.

Computer programs and data files were set up on the EPA National Computer Center IBM 370/168 computer to log sample receipt, and to produce report summaries which were sent to the NEWWA principal investigator for distribution to the field engineers for verification and reconciliation of discrepancies.

With the exception of pH, potentiometric alkalinity to the carbonic acid equivalence point, and potentiometric chloride determinations, all chemical analyses were performed by the DWRD, Inorganic and Particulate Control Section, analytical support group. A summation of the types of sample preservation used in the study is given in Appendix Table II-1. Table II-2 gives a broad overview of the types of analytical methods used, and Table II-3 gives specific method references. Details of the procedures themselves, plus documentation of the quality control and quality assurance procedures followed by the individual analysts of the analytical support group are given in the official Standard Operating Procedures document (24).

During the first round of sampling, the possibility of carefully preserving samples for pH analysis at the EPA Laboratory was investigated. Although that procedure had been used successfully before, Schock and Schock (25) warned of the necessity to determine the feasibility in each water quality situation before field measurements could be supplanted by delayed laboratory measurements.

Samples for pH analysis were collected in PVC or high-density, linear, polyethylene bottles having Poly-seal® caps and no air space. Upon receipt, the samples were analyzed according to the method of Schock & Schock (25), using digital meters and glass electrodes calibrated directly with buffer solutions prepared from NBS salts. The approach to pH equilibrium was monitored with strip chart recorders because the relatively poor buffering ability and low ionic strength of the waters caused long equilibration times.

In many cases, the laboratory pH was considerably different from that measured in the field, and the laboratory value was frequently higher. The idea of relying on laboratory measurements was thought to be unsuitable because depressurization during air shipment apparently could induce shifts in carbonate equilibria that would not occur during normal surface transport. A recent study on carbon isotope equilibria in aqueous samples supports this hypothesis (26). The pH values reported in Section 7 are the field measurements only.

The automated, colorimetric, analytical procedure routinely used for chloride determinations was known to have a detection limit in practice of approximately 10 mg/L which was too high for many samples. Thus, the implementation of the potentiometric titration method was planned for samples indicating less than 10 mg/L in the colorimetric test. Because a large proportion of the samples had chloride concentrations of less than 10 mg/L, and because discrepancies between the two methods were found for samples in the range of 5 to 10 mg/L, all chloride analyses were done by potentiometric titration starting with Round 2.

The inadequacies of an alkalinity titration to a fixed-pH end point are well-known. In order to obtain the most accurate data reasonably possible for this study and for future reference, an automated, microprocessor-controlled, potentiometric titration system (Metrohm E636 Titroprocessor® and auxilliary components) was employed. The carbonic acid equivalence points were determined with the proprietary algorithm supplied by the manufacturer for the instrument.

Quality Control

All blind unknowns were made from standards provided by either the USEPA Environmental Monitoring and Support Laboratory (EMSL) or the U.S. Geological Survey. There are important differences between the two types of standards, and, therefore, their utilization.

The standards provided by EMSL are small volumes in glass ampules that must be diluted accurately before submission. The standards have "true" values determined by the known amounts of chemicals contained in them. Three varieties were used; "trace metals," "minerals," and phosphate + nitrogen ("nutrients"). All were prepared by appropriate dilution in acid-washed, Class-A, volumetric glassware using Class-A transfer pipets and deionized-distilled water with a resistivity in excess of 16 megohms.

The U.S.G.S. standards are provided in natural matrices (river water, lake water, etc.) that were filtered, sterilized, acidified if necessary, and packed in Teflon bottles. Reference values are provided, plus standard deviations obtained by combining reports from numerous certified analytical laboratories for each constituent. Unlike the EMSL standards, the USGS ones do not provide "true" values against which the absolute accuracy of an individual laboratory's analytical methods can be firmly established. However, the analytical methods used in this study can be directly compared to accepted procedures, and accuracy within the standard deviations (or 2 times the standard deviations for a more liberal error allowance) would indicate good comparability with the practical state of the art.

Because of the organization of analyses in terms of sample preservation type, many of the EMSL or USGS standards could not provide certified values for more than a few constitutents. For instance, trace metal standards do not provide values for major constituents such as calcium and magnesium, but mineral standards don't cover trace metals or chlorides (the latter because of the aliquot from which it was taken for analysis).

A total of 33 blind unknowns prepared from either USGS or EMSL standards were submitted for this study. In addition, field duplicates were submitted from 5 sampling sites as a check of analytical and sampling reproducibility.

Alkalinity samples were analyzed as soon as possible after the samples were received. A total of 58 determinations were made on five different standards, and 84 samples were analyzed in duplicate. The observed and reference values for the determinations performed on the reference solutions are reported in Table II-4. An analysis of the standard deviations for the duplicated samples showed that the error distribution was nonnormal, and did not fit the assumption of an approximately constant relative standard deviation. As is shown in Table II-5, 50% of the alkalinity duplicates had a standard deviation of less than or equal to 0.082 mg/L as calcium carbonate, and 90% of the determinations had a standard deviation of better than 0.33 mg/L. Whereas the standard deviations are of limited significance as a result of the small number of replications, they indicate that the reported alkalinities can probably be considered to be precise and reliable to the first decimal place. The standard deviations calculated for the reference standards reinforce this interpretation. All alkalinity concentrations are reported in mg/L as calcium carbonate because this is usual water supply practice.

Because 2 mL of ultrapure grade HNO_3 were added per 100 mL of sample before analysis as a part of the normal analytical procedure, the aliquots for chloride analysis by potentiometric titration were generally taken from the acidified samples. When shortages of samples occurred, chloride analyses were done on aliquots from the unpreserved samples, however.

After an initial linearity test (27), chloride concentrations were determined by a linear regression procedure. The linearity test indicated a high bias below approximately 2.5 mg/L Cl^-. Therefore, any samples indicating less than 3 mg/L had a second aliquot analyzed after adding a 3 mg/L Cl spike. Volume and spike corrections were performed after the linear regression yielded the total concentration from the observed titration values. The results of the chloride determinations done on EMSL and USGS reference solutions are given in Table II-6.

Tables II-7 to II-11 contain tabulations of the analyses reported for the blind unknowns, along with the reference or true values for the standards used. Because of the use of high-quality deionized water and Class-A volumetric glassware for dilutions, the standard deviations given are those of the original reference adjusted only for the dilution factors.

Table II-12 summarizes the results of analyses of field duplicates. No spurious contamination or sampling inconsistancy is indicated for the techniques practiced at these sites.

A total of 12 acid and container "blanks" were also analyzed. From the lots of Cubitainers® and caps actually delivered to the field engineers, 24 containers were sent to the EPA laboratory. These samples were split into pairs and assigned EPA-9 sample numbers. Both containers were filled with Nanopure® deionized distilled water. One Cubitainer® from each pair was then acidified using an ampule of ultrapure HNO_3 from one of the two lots shipped to the sample collectors, and the acid lot was noted. Aliquots of unpreserved samples were spiked with 2 mL H_2HO_4 before NO_3-N and fluoride analyses.

Table II-13 gives a summary of the "calibration limits" obtained in practice with the analytical procedures used in this study. The "calibration limit" as applied to this study indicates the lowest level of a constituent that is adequately covered by an instrumental calibration standard, and below which no quantitation will be made. The calibration limits are higher than limits of detection and limits of quantitation (LOQ) as rigorously defined (28). The calibration limits as reported here are related to limits of detection and limits of quantitation in that they are at least at the LOQ, although many are somewhat higher, and represent compromises between speed of analysis and concentration level necessary to provide useful environmental information.

In only two of the blanks did any constituent have a value in excess of the indicated calibration limit reported for it. In both cases, the constituent was iron, and the reported concentrations were 0.11 and 0.15 mg/L. These may not represent true concentrations, considering the scale of the scatter in the values determined for the blind unknowns. The blank data indicate that little or no detectable contamination should be expected from either the containers or acids used in this study.

SECTION 6

REVIEW OF ANALYTICAL METHODOLOGY

LAWRENCE EXPERIMENT STATION

A review of methodology for water analysis must include a study of Standard Methods for the Examination of Water and Waste Water (29), the development of which was contributed to significantly by researchers at the Lawrence Experiment Station, Lawrence, Massachusetts. During this project, investigators found at the Station a large quantity of historical data on water quality. One objective of the project was to evaluate this information to determine if raw water quality changes had occurred during the 20th Century. As these data form the core of the review of historical data in this report the following discussion on changes in chemical analytical methodology will make several references to what happened at Lawrence.

The Massachusetts State Board of Health was created in 1869. The Board obtained use of the Essex Company hydraulic laboratory in Lawrence, which was the beginning of the Lawrence Experiment Station. Studies there on sewage purification by filtration led to application of the findings to filtration of water, resulting in the use of slow sand filtration at Lawrence in 1893.

In 1889 the Board published The Chemical Examination of Waters (30) which described in detail the methods then available for water chemistry. These procedures were followed at the laboratories at the State House and MIT that later became the associated with the Lawrence Experiment Station. The first edition of Standard Methods of Water Analysis was published in 1905 (31). Analysts who worked at Lawrence contributed heavily to this first edition. From that day to the present, drinking water analyses performed at or under the supervision of the Lawrence Experiment Station have been performed, with few exceptions, in accordance with Standard Methods.

Chemical analyses and biological examinations of drinking waters were performed by scientists at the Massachusetts Institute of Technology until 1896, at which time a water laboratory was set up in the State House where procedures and personnel were under the supervision of the Lawrence Experiment Station Staff. Operations were transferred to the new Station in 1953. Table 5 shows water supplies for which histrical data were obtained at Lawrence.

Analytical procedures in water chemistry have changed through the years. As changes occurred, they were noted in the records at Lawrence.

TABLE 5. MASSACHUSETTS COMMUNITIES FOR WHICH HISTORICAL INFORMATION WAS AVAILABLE AT THE LAWRENCE EXPERIMENT STATION, LAWRENCE, MASSACHUSETTS

Community	Water Source	Historical Records* Available From
1) Athol	Phillipston Reservoir	1887
2) Boston MDC	Quabbin Reservoir	1944
	Wachusett Reservoir	1898
3) Cambridge	Hobbs Brooks Reservoir	1894
4) Dalton	Egypt Brook Reservoir	1888
5) Fall River	North Wattuppa Pond Reservoir	1887
6) Falmouth	Long Pond Reservoir	1891
7) Fitchburg	Lovell Reservoir	1930
8) Gardner	Crystal Lake Reservoir	1888
9) Glouster	Dykes Reservoir	1887
	Haskell Reservoir	1895
10) Hinsdale	Belmont Reservoir	1889
11) Holyoke	Carmody Reservoir	1895
12) Lakeville	Assawompsett Reservoir	1888
13) Leominster	Fall Brooke Reservoir	1895
14) Lee	Upper Codding Brook Reservoir	1887
15) Montague	Lake Pleasant Reservoir	1887
16) Pittsfield	Farnham Reservoir	1913
17) Salem-Beverly	Longham Reservoir	1893
	Wenham Lake	1887
18) Southbridge	Hatchet Brook Reservoir	1893
19) Spencer	Shaw Pond Reservoir	1888
20) Springfield	Cobble Mountain Reservoir	1932
21) Westfield	Montgomery Reservoir	1888
22) Winchendon	Winchendon Well	1888
	Upper Naukeag Lake Reservoir	1888
23) Worcester	Pine Hill Reservoir	1923
24) New Bedford	Little Quitticas Pond	1888

*See Table 6 for further data on which analysis were begun at what date.

According to these records, for example, in determining alkalinities methyl orange indicator was used at Lawrence from 1936 to 1976; since then, the potentiometric method to pH 4.5 had been used. In both cases, standard alkalinity solutions were used to standardize the acid used for titration. From 1935 to 1953, pH was determined colorimetrically on a 10-mL sample treated with 0.5 mL of Bromothymol Blue indicator; from 1953 by the glass electrode method. Test procedures were checked against standard buffers. From 1888 through 1952 the soap method was used for hardness; then, the EDTA procedure through 1972 and after that atomic absorption spectrophotometry. Prior to 1972, sulfate was measured gravimetrically by precipitation with barium chloride; after 1972 by the Hach Sulfa-Ver® method. Nitrate measurements were begun in 1887, with breaks from 1915 to 1935 and from 1949 to 1961. Up to 1965 the phenoldisulfonic acid method was used, then the hydrazine method.

The three most important tests made in this study are for pH, alkalinity and calcium. Sulfate, aluminum, lead and mercury concentrations are important also, but historical records of these constituents are scarce compared to those for pH, alkalinity, and calcium. Records of calcium and magnesium in the past are not as numerous as pH and alkalinity. However, the amount of hardness furnishes a means of approximating the calcium content, which together with pH and alkalinity provides parameters whereby the calcite saturation index (CSI), a measure of the susceptibility to acid loading, may be calculated. For example, historical data from Beverly-Salem, Massachusetts shows values for calcium, magnesium and hardness as follows:

Year	Ca mg/L	Mg mg/L	Hardness mg/L		C/Hardness Ratio
1973	13	3.6	48		0.2708
1974	12	3.2	43		0.2790
1975	12	3.2	44		0.2727
1976	12	3.1	42		0.2857
1977	10	2.7	36		0.2777
1978	10	2.6	36		0.2777
1979	11	2.9	39		0.2820
				Mean	0.2779

An equation developed by the former Chief Chemist of the Providence, Rhode Island Water Department for calcium and magnesium and hardness of New England water is:

$$\text{Hardness} = 2.479\ \text{Ca} + 4.116\ \text{Mg} \qquad (5)$$

$$\text{Calcium} = \frac{\text{Hardness} - 4.116\ \text{Mg}.}{2.497} \qquad (6)$$

Hardness, Ca and Mg are in mg/L

Using this formula with actual hardness values the calcium values in column (4) were derived. Using a calcium/hardness ratio the figures in column (5) were obtained. The latter, simpler calculations were used through the report.

Year	Actual Hardness in mg/L	Calcium	Calculated Calcium mg/L	
(1)	(2)	(3)	(4)	(5)
1973	48	13	13.29	13.3
1974	43	12	11.95	11.9
1975	44	12	12.35	12.2
1976	42	12	11.71	11.7
1977	36	10	9.97	10.0
1978	36	10	10.13	10.0
1979	39	11	10.84	10.8

In both cases there was close agreement with actual calcium determinations for each of the seven years 1973-1979.

COMPARING OLD AND NEW DATA

Kramer and Tessier (32) give equations for correcting pH values measured colorimetrically to what they would have been if determined by a modern pH meter. An example of their use is the following:

Assume a New England surface water with an alkalinity of 19 ueq/L, roughly 1 mg/L as $CaCO_3$, and a pH of 6.2. At this low alkalinity, all of the alkalinity may be considered to be bicarbonate (HCO_3^-). Using Kramer and Tessier's equation (35) in Reference 32:

$$[H^+]s = \left[\frac{C_I V_I \; [H^+]c}{[H^+]_c + K_I}\right]\left[\frac{[H^+]c + K1_1}{V[Alk]}\right] + [H^+]_c, \text{ where} \tag{7}$$

$C_I = 0.64\text{x}10^{-3}$ M; $V_I = 5\text{x}10^{-4}$L; $[H^+]c = 63\text{x}10^{-8}$; $K_I = 10^{-7.1}$;

$K_1 = 10^{-6.35}$; $V = 10^{-2}$ L and $[Alk] = 19\text{x}10^{-6}$.

$$[H^+]s = \left[\frac{(0.64\text{x}10^{-3})(5\text{x}10^{-4})(63\text{x}10^{-8})}{63\text{x}10^{-8+} + 7.94\text{x}10^{-8}}\right]\left[\frac{(63\text{x}10^{-8}+45\text{x}10^{-8}}{(10^{-2} \; (19\text{x}10^{-6}}\right] + 63\text{x}10^{-8}) \tag{8}$$

$[H^+]s = 223 \text{ x } 10^{-8}$

pHs = negative logarithm of $223\text{x}10^{-8} = 5.65$

$[H^+]c = [H^+]$ determined colorimetrically $\frac{(1)}{(\text{antilog pHc})}$. (9)

$[H^+]s$ = corrected $[H^+]$ (The true $[H^+]$ of the sample).

pHs = corrected pH (The true pH of the sample).

In the above calculation, the value of K at 25°C ($10^{-6.35}$), or 45×10^{-8}, was used and unit activity was assumed. The corrected pH of 5.7 is to be compared with a present day pH as determined by the glass electrode method.

Calcium concentrations may be approximated based upon hardness data. By using the ratio of calcium to hardness as determined by analyses for the period from 1973 to the present, hardness concentrations may be used to estimated mg/L of calcium for the years prior to 1973. For example, the average calcium and hardness for Wenham Lake, Salem, Massachusetts for 1973-1980 were 11.4 mg/L and 41 mg/L, as $CaCO_3$, respectivately. The ratio of calcium to hardness would be 0.28. For Cobble Mountain Reservoir, Springfield, Massachusetts, the ratio is 0.25 and for Middle Reservoir, Northampton, Massachusetts, the ratio is 0.30. Assuming that calcium to hardness ratios in the past were relatively the same as for 1973-1980, which is reasonable for undisturbed watersheds, the following calcium concentrations may be estimated for Wenham Lake:

1888	5.3 mg/L	1931-1940	8.1 mg/L
1890	7.0 mg/L	1941-150	8.1 mg/L
1891-1900	7.0 mg/L	1951-1960	9.2 mg/L
1901-1910	6.2 mg/L	1961-1970	13.2 mg/L
1911-1920	7.3 mg/L	1971-1972	13.0 mg/L
1921-1930	7.6 mg/L	1973-1980	11.4 mg/L*

*The last value was the actual concentration determined by atomic adsorption for 1973-1980.

It may be argued that because the soap method for hardness measures the soap consuming capacity of a water whereas the EDTA procedure complexes all calcium and magnesium, hardness values determined by these two methods would not be comparable. However, the Wenham hardness data of 32 mg/L as $CaCO_3$ for 1949 and 35 mg/L for 1952 (data not available for 1950 and 1951), the last years using the soap method, compare favorably with the average of 33.5 for the years 1953-1956, inclusive, i.e., no change in hardness when averaging the results of the first four years using the EDTA method. Correspondingly, for 1971 and 1972, the last years using the EDTA method, the average hardness was 46.5 compared to 45.5 for the first two years, 1973 and 1974, when atomic absorption technique was adopted. Changes in procedures did not seem to affect the accuracy of the hardness measurements at Wenham Lake as determined by the Lawrence Experiment Station.

Even if considerable error resulted from estimating calcium by multiplying the hardness by the appropriate calcium to hardness ratio as previously described, a negligible difference in the CSI would result. For example, assume a correct value of 4 mg/L for calcium and an estimated one of 3 mg/L (33 percent error). The negative logarithm of moles/L of calcium would be 4 and 4.123, respectively ... the difference of 0.12 would amount to only three percent for a water having a CSI of 4.

Another water quality characteristic, measured from 1887 to 1941, inclusive, was residue on evaporation. Because of the small amount of suspended matter and low turbidity of the samples, residue on evaporation may be considered to be an approximate measure of the total dissolved solids. No data exist for the years 1942-1982, inclusive. Specific conductance determined during the years 1972 to the present affords a means of arriving at a crude estimate of the total dissolved solids (TDS) for 1972 and later. The average specific conductance for 1972-1980, the latest year for which data are available, amounted to 169 umho/cm. Using Langelier's approximation (15), the ionic strength, u, may be calculated from the equation $u = 2.5 \times 10^{-5} \times TDS$. Russell (33) derived the following expression equating u to specific conductance; $u = 1.6 \times 10^{-5}$ x specific conductance. Combining these two equations mg/L TDS = 0.64 x specific conductance. Use of data provided by Lind (34) gives an equation similar to that of Russell.

An examination of the records covering Wenham Lake show an average residue on evaporation (TDS) of 66 mg/L for 1887-1941, inclusive. The average specific conductance being 170 umho/cm for 1972 through 1980, gives a rough estimate of 170x0.64, or 110 mg/L TDS. This is an increase of about 64 percent over the 1887-1941 average. A breakdown of the data shows: for 1887 through 1890, an average of 45 mg/L TDS; for 1891-1900, 57 mg/L; 1901-1910 (two years of data not available), 57 mg/L; 1911-1920, 74 mg/L; 1921-1930, 75 mg/L; 1931-1941, 72 mg/L.

Changes in the methodology for residue on evaporation were made throughout the years by Standard Methods (29). They apply mostly to the temperature of drying the residue. In 1890 the drying temperature following evaporation of a known volume of water in a weighed platinum dish was specified as 100°C.

In 1905 the drying temperature required was 103°C, together with the provision that the dish be surrounded by boiling glycerin solution or toluene in the oven. In 1917 came the option of using a drying temperature of 103°C or 180°C. Drying time was increased from one-half to one hour. The necessity for glycerin or toluene was dropped in 1920. Drying temperature in 1923 was 180°C; in 1933 it was decreased to 103°C. The 1980 edition of Standard Methods states: "The methods described are gravimetric and permit a choice of drying temperature. Residues dried at 103°C to 105°C may retain not only water of crystallization but also some mechanically occluded water. Loss of CO_2 will result in coversion of bicarbonate to carbonate. Loss of organic matter by volatilization usually will be very slight at this temperature. Because removal of occluded water is marginal at 105°C, attainment of constant weight is very slow."

Residues dried at 180 ± 2°C will lose almost all mechanically occluded water. Some water of crystallization may remain, especially if sulfates are present. Organic matter is lost by volatilization but is not completely destroyed. Bicarbonates are converted to carbonates and carbonates may be decomposed partially to oxides or basic salts. Some chloride and nitrate salts may be lost. In general, evaporation and drying water samples at 180°C yields values for total residue closer to those obtained through summation of individually determined mineral species than the values for total residue secured through drying at a lower temperature.

TDS values are used in computation of the Langelier Index. A review of the data obtained in this study indicates that with regard to calculation of the LI, the TDS data do not include a range broad enough to influence LI values.

Characteristics in addition to those mentioned were measured, such as color (1887-1982), chlorides (1887 through 1953 and 1962 through 1982), Iron (1893, 1923 through 1949 and 1965 through 1982), Manganese (1935 through 1939 and 1965 through 1982), turbidity (1969 through 1982, magnesium (1973 through 1979), sodium (1972 through 1982), potassium (1972 through 1982), silicon (1972 through 1982), copper (1973 through 1982). Although important, these are not as vital in assessing the impact of acid precipitation as alkalinity, pH and calcium, together with sulfate and nitrate. Table 6 summarizes various analyses that have been used at the Lawrence Experiment Station throughout the past century of activity.

TABLE 6. DATA ON HISTORICAL METHODOLOGY AT LAWRENCE EXPERIMENT STATION, LAWRENCE, MASSACHUSETTS

Determination	Date Conducted	Methodology	Standard Method Edition*
Alkalinity	1936-1976	Methyl Orange	8 to 14
	1976-1983	Potentiometric to pH 4.5	14,15
pH	1935-1953	Colorimetric; bromthymol blue	7 to 9
	1953-1983	Glass Electrode	9 to 15
Hardness	1888-1952	Soap method	1 to 9
	1952-1972	EDTA method	9 to 13
	1972-1983	Atomic absorption	13 to 15
Sulfate	1972-1972	Gravimetric with $BaCl_2$	13
	1972-1983	Hach Sulfa-Ver (Not a Standard Method)	-
Nitrate	1887-1965	Phenoldisulfonic acid method	1 to 12
	1965-1983	Hydrazine method	12 to 15
Manganese	1935-1965	Periodate & persulfate methods	7 to 11
	1965-1971	Orthotolidine method	12
	1971-1983	Atomic Absorbance	13 to 15
Chloride	1887-1912	Concentration by evaporation; precipitation as HgCl.	1,2
	1912-1946	Same but gravimetric when $Cl^- > 1000$ ppm.	3 to 8
	1946-1955	Volhard method; Mohr method.	9
	1955-1975	Same; $Hg(NO_3)_2$ method introduced	10 to 13
	1975-1980	Same; potentiometric method.	14,15
	1980-1983	Same; Automated ferric cyanide method	15
Color	1887-1905	Description	1
	1905-1975	Cobalt chloride standards	1 to 13
	1975-1983	Spectrophotometer method using Tristimulus light filters.	14,15
Iron	1905-1912	Evaporation, ignition, acidification, add $KMnO_4$ and potassium thiocyanate. Color comparisons.	1
	1912-1946	Same but concentrated HCl used in standards.	2 to 8
	1946-1971	Bioglpyridine & Phenanthroline method	9 to 12
	1971-1983	Phenanthroline and atomic absorption methods.	13 to 15

*Not necessarily the first issue in which the method appeared.

Note: After Standard Methods were published the methodology cited above was in accordance with those Methods except for sulfate (1972-1983).

SECTION 7

PRESENT DAY WATER QUALITY

This section of the report presents results of analyses of water samples collected during this study. Data are given for pH, alkalinity, calcium, sulfate and the four indices previously described (Langelier Index, Ryznar's Stability Index, Aggressive Index, and Calcite Saturation Index). Data are also presented for constituents for which EPA has established MCL's (arsenic, barium, cadmium, lead, mercury, selenium, and nitrate) and SMCL's (pH, copper, iron, and zinc). In addition, data are shown for aluminum. Results are given for Round 1, Round 2, and Round 3, after which data on tap water quality are tabulated. Interested readers also will find these data plus data not published in this report in Volume II, Appendix (35).

ROUND 1: NEW ENGLAND AND NY

Tables 7-10 show data from Round 1 of the project, namely the results of analyses of samples collected from surface sources in New England and the Adirondack area of New York State. Data are for pH, alkalinity (Alk), calcium (Ca), and sulfate (SO_4). The pH of raw water was seldom below 5.0 for raw waters, but almost half of the raw surface water alkalinities were below 5 mg/L as $CaCO_3$, and well over half of the raw surface waters had calcium concentrations below 5 mg/L. The raw ground waters were higher in alkalinity and calcium than the surface waters. One fifth or more of the finished waters from both ground and surface sources fell outside the pH range in the SMCL.

Figures 3 and 4 contain data from Round 1 surface and groundwater supplies calculated in terms of Calcite Saturation Index (CSI), Stability Index (SI), Langelier Index (LI) and Aggressive Index (AI). Three fourths of the raw waters had Stability Index values of 11 or higher. None of the waters in Round 1 had SI values in the range for which scaling was reported by Ryznar (17). Less than 10 percent of the LI values indicated a possibility of deposition. Changes in the quality indices of raw vs. finished waters were more pronounced for ground water supplies than for surface water supplies.

Data for aluminum and for inorganic substances for which EPA has established health-related MCL's are shown in Tables 11 and 12. Only three constituents met or exceeded the MCL. This happened one time for arsenic, once for lead, and once for mercury, all in surface waters (Table 11). No MCL violations were observed in the smaller number of ground waters analyzed (Table 12).

TABLE 7. DISTRIBUTION OF pH

ROUND 1 - GROUND & SURFACE

pH Range Interval	Percent of Samples In Range Interval			
	Surface Raw	Surface Finished	Ground Raw	Ground Finished
4.0-4.9	4	8	0	0
5.0-5.9	18	11	42	20
6.0-6.9	62	47	33	30
7.0-7.9	14	17	25	50
8.0-8.9	2	12	0	0
9.0-9.9	0	5	0	0
Geometric Mean	5.79	5.57	5.72	6.28
Median	6.56	6.66	6.07	6.97
Standard Dev.	0.711	1.14	0.838	0.77
Range	4.3-8.45	4.25-9.77	5.15-7.8	5.72-7.81
No. of Samples	118	98	12	10

All values for ground and surface water are expressed in percent of occurrences in each category.

TABLE 8. DISTRIBUTION OF ALKALINITY

ROUND 1 - GROUND & SURFACE

Alkalinity Range Interval mg/L as $CaCO_3$	Percent of Samples In Range Interval			
	Surface Raw	Surface Finished	Ground Raw	Ground Finished
0-4	41	29	8	10
5-9	28	26	8	
10-19	10	22	25	
20-39	13	16	25	30
40-79	6	5	8	20
80-119	1	0	8	20
120-159	1	2	8	10
160-199	1	0	8	10
Mean	15.02	16.24	47.5	67.2
Median	6.1	7.5	23.4	50.6
Standard Dev.	24.2	22.43	53.5	53.1
Range	0-167.3	0-141	3-161.6	2.7-167
No. of Samples	120	102	12	10

(mean, median, SD and range are in mg/L)

TABLE 9. DISTRIBUTION OF CALCIUM

ROUND 1 - GROUND & SURFACE

Calcium Range Interval mg/L	Percent of Samples In Range Interval			
	Surface Raw	Surface Finished	Ground Raw	Ground Finished
0-4	68	58	17	10
5-9	14	20	33	10
10-19	12	17	25	40
20-29	3	5	0	10
30-39	2	1	8	10
40-49	1	0	8	10
50-59	0	0	8	0
60-69	0	0	0	10
Mean	6.07	7.14	17.5	21.9
Median	3.35	4.05	9.95	14.3
Standard Dev.	6.96	6.86	17.8	18.4
Range	0.9-41.1	<0.5-31.4	3.4-58.6	1.8-60.6
No. of Samples	120	102	12	10

(mean, median, SD and range are in mg/L)

TABLE 10. DISTRIBUTION OF SULFATE

ROUND 1 - GROUND & SURFACE

Sulfate Range Interval mg/L	Percent of Samples In Range Interval			
	Surface Raw	Surface Finished	Ground Raw	Ground Finished
0-9	78	62	42	50
10-19	19	18	50	40
20-29	2	11	0	0
30-39	1	5	0	0
40-49	0	2	8	10
50-59	0	0	0	0
60-69	0	1	0	0
70-79	0	1	0	0
Mean	8.13	12.83	11.58	12.9
Median	7	7.5	10.5	10
Standard Dev.	4.72	12.07	10.1	10.28
Range	3-37	3-73	1-40	4-40
No. of Samples	119	102	12	10

(mean, median, SD and range are in mg/L)

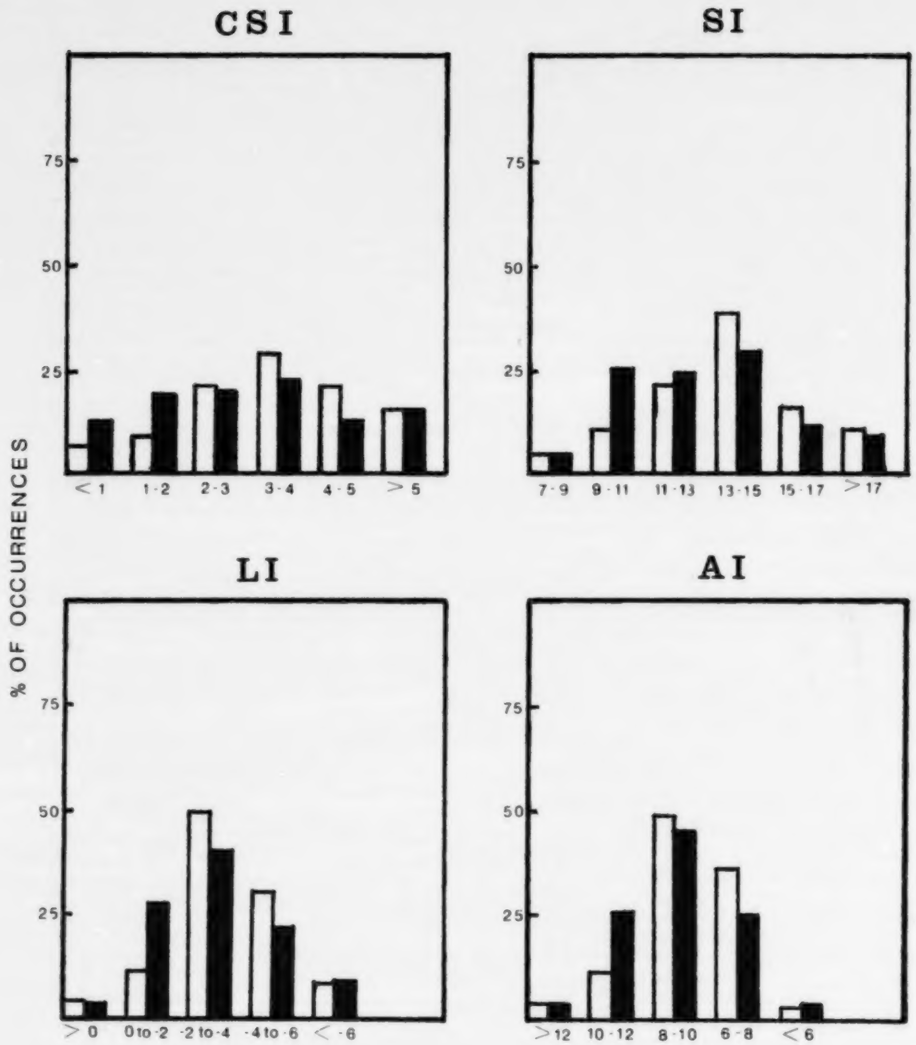


FIGURE 3. COMPARISON OF SURFACE WATERS - RAW AND FINISHED ROUND 1

☐ RAW ■ FINISHED

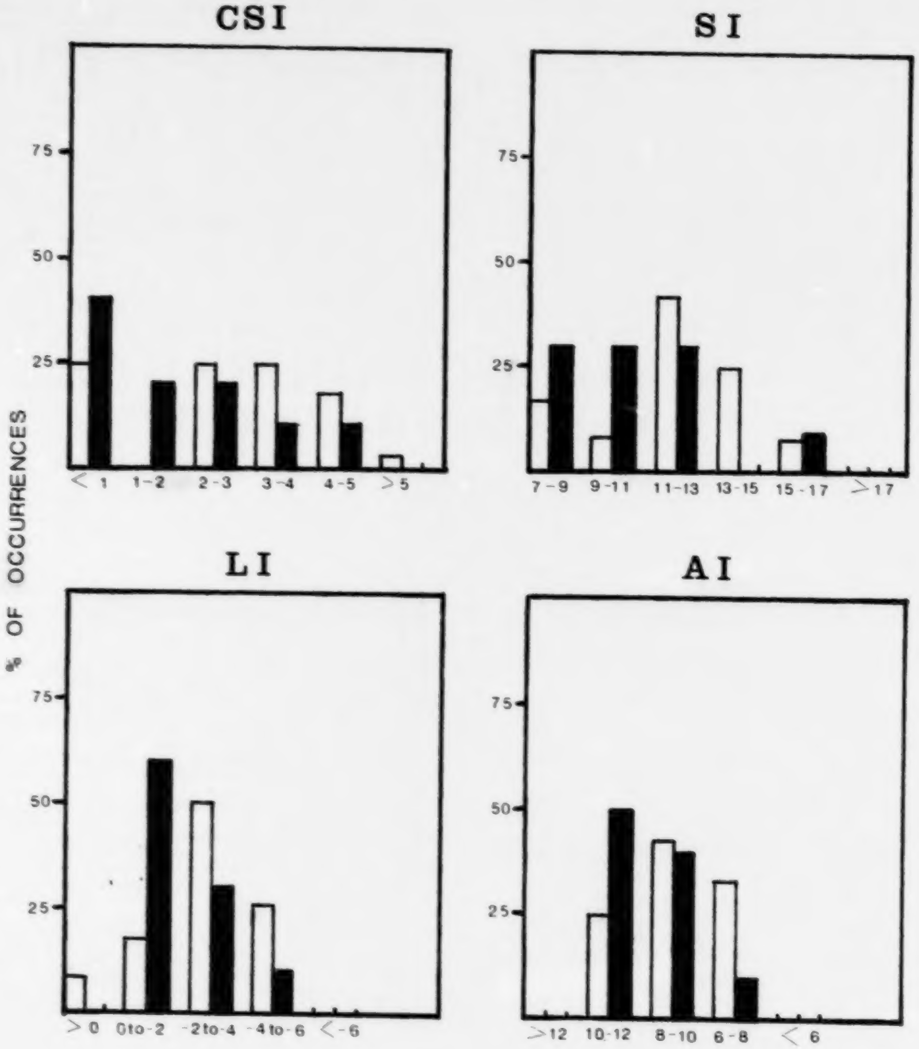


FIGURE 4. COMPARISON OF GROUND WATERS - RAW AND FINISHED ROUND 1

☐ RAW ■ FINISHED

TABLE 11. TOXIC ELEMENT DATA

ROUND 1 SURFACE SUPPLIES
RAW AND FINISHED WATER

Compound or Element	MCL in mg/L	Number of tests (N)		Analytical Range		No. of tests >MCL	
		Surface Raw	Surface Finished	Surface Raw	Surface Finished	Surface Raw	Surface Finished
Arsenic	0.05	118	101	<0.005-0.012	<0.005-0.053	0	1
Barium	1	118	101	<0.2-0.53	<0.2-0.41	0	0
Cadmium	0.010	120	101	<0.002-0.006	<0.002	0	0
Lead	0.05	119	101	<0.005-0.018	<0.005-0.202	0	1
Mercury	0.002	120	101	<0.0005-0.0049	<0.0005	1	0
Selenium	0.01	117	101	<0.005-0.007	<0.005	0	0
Aluminum	NONE	120	100	<0.1-0.3	<0.1-0.5	-	-
Nitrate as N	10	118	100	<0.3-0.6	<0.3-1.3	0	0

TABLE 12. TOXIC ELEMENT DATA

ROUND 1 GROUND SUPPLIES
RAW AND FINISHED WATER

Compound or Element	MCL in mg/L	Number of tests (N)		Analytical Range		No. of tests >MCL	
		Ground Raw	Ground Finished	Ground Raw	Ground Finished	Ground Raw	Ground Finished
Arsenic	0.05	11	10	<0.005-0.006	<0.005-0.008	0	0
Barium	1	12	10	<0.2-0.42	<0.2-0.42	0	0
Cadmium	0.010	12	10	<0.002	<0.002-0.008	0	0
Lead	0.05	12	10	<0.005-0.009	<0.005-0.005	0	0
Mercury	0.002	12	10	<0.0005	<0.0005	0	0
Selenium	0.01	11	10	<0.005	<0.005	0	0
Aluminum	NONE	12	10	<0.1-0.3	<0.1-0.2	-	-
Nitrate as N	10	12	10	<0.3-3.5	<0.3-1.2	0	0

ROUND 2: NEW ENGLAND AND NY

Round 2 results are given in terms of comparisons of raw water characteristics for ground and surface supplies and also comparisons of raw and finished water quality of surface water. Tables 13 through 16 compare data distributions, in terms of percent, for pH, alkalinity, calcium and sulfate of raw water from ground and surface water supplies covered in Round 2 of the survey. The contrast in the quality of raw ground and surface water was more pronounced in Round 2 although about half of the raw waters from both sources had pH values below 6.5, the SMCL lower level. A smaller proportion of treated water pH values fell outside of the SMCL range. Surface water pH values tended to be somewhat lower, but calcium, alkalinity and sulfate were markedly lower in surface waters. The great majority of surface water alkalinities were less than 5 mg/L as $CaCO_3$, and over 90 percent of the calcium concentrations were under 5 mg/L.

A similar comparison is made for raw and finished surface waters as detailed in Tables 17 through 20. The quality changes observed for finished water could result from contact of the water with pipes and structures in which it is conveyed, treated, and stored, or the changes could be caused by deliberate additions of chemicals to modify water quality. Data obtained in Round 2 were used to calculate the quality indices of concern: LI, SI, AI, and CSI. Data comparing Round 2 ground and surface raw water supplies in terms of these indices are given in Figure 5. In similar manner the CSI, SI, LI and AI values for Round 2 raw and finished surface water are presented in Figure 6. The data for pH, alkalinity, calcium and sulfate in finished ground waters are given in Table 21. Corresponding index values are in Table 22.

All raw surface waters and nearly all raw ground waters had qualities that favored dissolution of calcium carbonate (Fig. 5). The tendency to dissolved calcium carbonate was decreased slightly in the finished surface waters as compared to raw surface waters (Fig. 6).

Data for aluminum and for inorganic substances for which EPA has set MCL's are present in Tables 23 (surface water) and 24 (ground water). The MCL's for arsenic, cadmium, lead and selenium were exceeded once in the finished surface waters. Mercury exceeded the MCL once in a raw water sample. In raw ground waters, MCL's were exceeded once for lead, once for nitrate, and twice for selenium. The MCL for lead was exceeded one time in finished ground water.

ROUND 3: MA, NJ, PA, WV, VA, NC

The third round of sampling was from groundwaters in the states of New Jersey, Pennsylvania, West Virginia, Virginia, North Carolina and the Massachusetts island of Martha's Vineyard. In the tables and histograms which follow test results information has been separated on the basis of Coastal (New Jersey and Martha's Vineyard) and Appalachian (Pennsylvania, West Virginia, Virginia and North Carolina sources. All water tests reported upon in this section were samples from untreated supplies. Differences were found in water quality in the Appalachian chain and the Coastal region.

TABLE 13. COMPARISON OF GROUND AND SURFACE RAW WATER pH VALUES

ROUND 2

Range Interval pH	Percent of Tests in Range Interval Ground	Surface
4.0-4.9	4	16
5.0-5.9	41	36
6.0-6.9	44	43
7.0-7.9	6	5
8.0-8.9	5	0
G. Mean	5.57	5.06
Median	6.04	5.83
Stand. Dev.	0.81	0.81
Range	4.1-8.53	4.0-7.2
No. of Samples	84	42

TABLE 14. COMPARISON OF GROUND AND SURFACE RAW WATER ALKALINITY VALUES

ROUND 2

Range Interval Alkalinity (mg/L as $CaCO_3$)	Percent of Tests in Range Interval Ground	Surface
0-4	3	86
5-9	22	7
10-19	34	2
20-39	17	2
41-80	13	2
81-120	5	0
121-160	0	0
161-200	5	0
Mean	32.04	*5.63
Median	17	2.16
Stand. Dev.	39.50	*8.84
Range	2-200	0-44.9
No. of Samples	87	42

*These values determined with 30 samples - 12=<0.1 or <1 or 0

Note: Mean, median, standard deviation and range are in mg/L.

TABLE 15. COMPARISON OF GROUND AND SURFACE RAW WATER CALCIUM VALUES

ROUND 2

Range Interval Calcium (mg/L)	Percent of Tests in Range Interval Ground	 Surface
0-4	19	93
5-9	41	2
10-19	26	2
20-29	7	2
30-39	1	0
40-49	5	0
50-69	1	0
Mean	12.23	3.71
Median	8.9	2.4
Stand. Dev.	11.79	4.55
Range	1.0-68.6	1.1-25.9
No. of Samples	83	42

Note: Mean, median, standard deviation and range are in mg/L.

TABLE 16. COMPARISON OF GROUND AND SURFACE RAW WATER SULFATE VALUES

ROUND 2

Range Interval Sulfate (mg/L)	Percent of Tests in Range Interval Ground	 Surface
0-9	47	86
10-19	41	10
20-29	9	2
30-39	1	0
40-49	1	0
50-59	1	2
Mean	12.39	8.5
Median	10	7
Stand. Dev.	8.53	7.64
Range	2-56	3-50
No. of Samples	83	42

Note: Mean, median, standard deviation and range are in mg/L.

TABLE 17. DISTRIBUTION OF pH

ROUND 2 - RAW AND FINISHED SURFACE

Range Interval pH	Percent of Tests in Range Interval Raw Surface	Finished Surface
4.0-4.9	16	18
5.0-5.9	36	12
6.0-6.9	43	37
7.0-7.9	5	15
8.0-8.9	0	9
9.0-10.9	0	9
G. Mean	5.06	5.35
Median	5.83	6.46
Stand. Dev.	0.81	1.54
Range	4.0-7.2	4.42-10.41
No. of Samples	42	33

TABLE 18. DISTRIBUTION OF ALKALINITY

ROUND 2 - RAW AND FINISHED SURFACE

Range Interval Alkalinity (mg/L as $CaCO_3$)	Percent of Tests in Range Interval	
	Raw Surface	Finished Surface
0-2.4	60	39
2.5-4.9	26	15
5.0-9	7	24
10-19	2	15
20-39	2	6
40-49	2	
Mean	*5.63	**7.25
Median	2.16	3.5
Stand. Dev.	*8.84	**6.84
Range	0-44.9	<0.1-31.4
No. of Samples	42	33

Note: Mean, median, standard deviation and range are in mg/L.

* 12% raw alk=0 or <0.1 so couldn't be included in these computations.

** 7 of finished alk values=<0.1 so couldn't be included in these computations.

TABLE 19. DISTRIBUTION OF CALCIUM

ROUND 2 - RAW AND FINISHED SURFACE

Range Interval Calcium (mg/L)	Percent of Tests in Range Interval Raw Surface	 Finished Surface
0-4.9	94	85
5-9.9	2	15
10.0-14.9	0	0
15.0-19.9	2	0
20.0-24.9	0	0
25.0-29.9	2	0
Mean	3.71	3.32
Median	2.4	2.6
Stand. Dev.	4.55	2.22
Range	1.1-25.9	0.5-9.5
No. of Samples	42	33

Note: Mean, median, standard deviation and range are in mg/L.

TABLE 20. DISTRIBUTION OF SULFATE

ROUND 2 - RAW AND FINISHED SURFACE

Range Interval Sulfate (mg/L)	Percent of Tests in Range Interval Raw Surface	Finished Surface
0-9	86	72
10-19	10	22
20-29	2	3
30-39	0	3
40-49	0	0
50-59	2	0
Mean	8.5	9.31
Median	7	7
Stand. Dev.	7.64	6.52
Range	3-50	4-31
No. of Samples	42	32

Note: Mean, median, standard deviation and range are in mg/L.

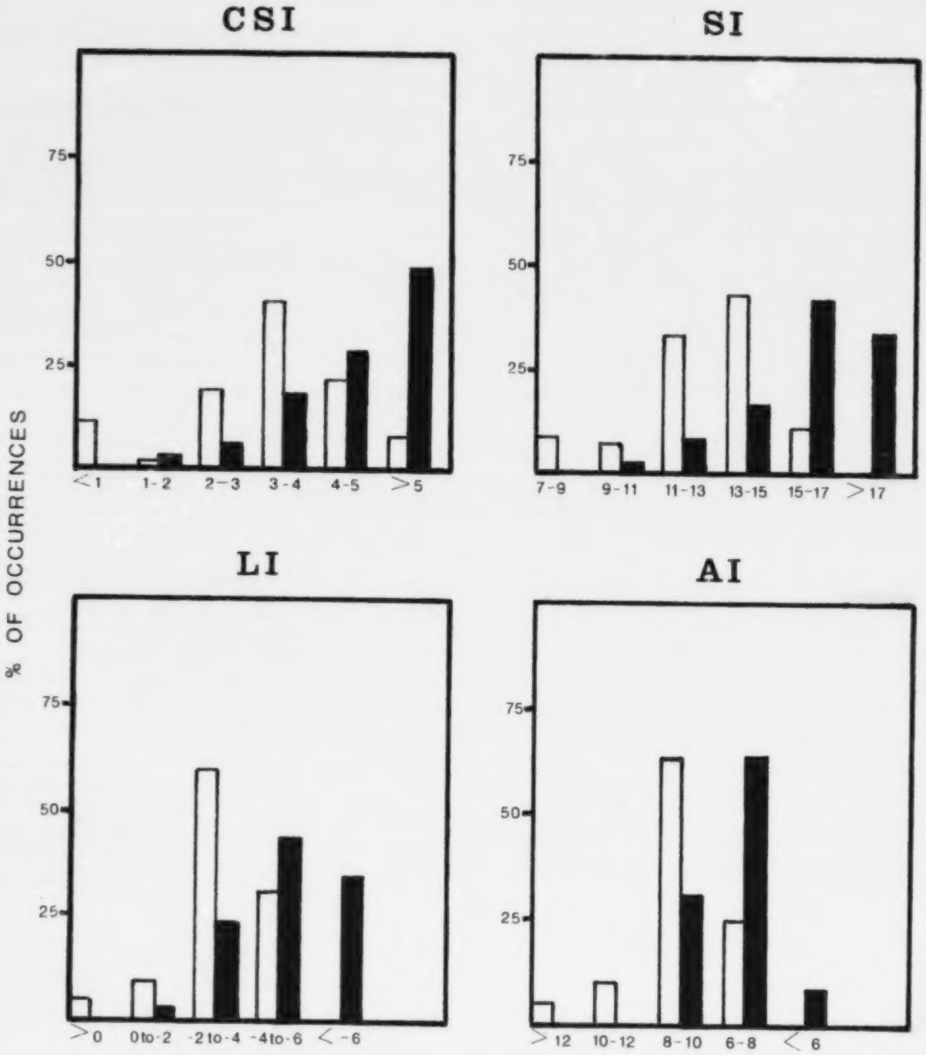


FIGURE 5. COMPARISON OF RAW WATERS — ROUND TWO

☐ GROUND ■ SURFACE

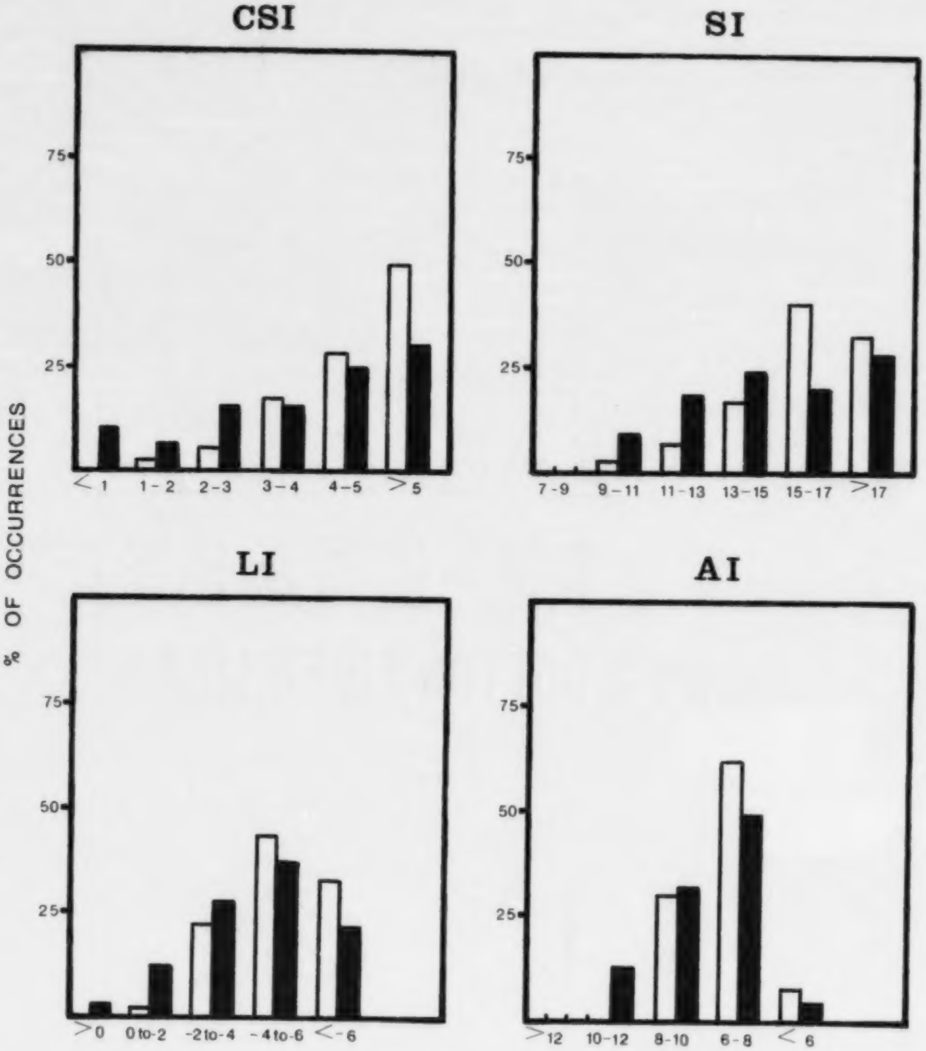


FIGURE 6. RAW AND FINISHED SURFACE WATERS — ROUND 2

☐ RAW ■ FINISHED

TABLE 21. DISTRIBUTION OF pH, ALKALINITY, CALCIUM AND SULFATE

ROUND 2 - FINISHED GROUNDWATER

pH	% of Tests	Alk (mg/L as $CaCO_3$)	% of Tests	Ca (mg/L)	% of Tests	SO_4 (mg/L)	% of Tests
4.0-4.9	9	0-9	27	0-4	33	0-9	42
5.0-5.9	9	10-19	27	5-9	25	10-19	42
6.0-6.9	55	20-29	28	10-14	33	20-29	0
7.0-7.9	18	30-39	0	15-19	0	30-39	8
8.0-8.9	9	40-49	9	20-24	9	40-49	0
		50-59	9			50-69	8
Mean	5.76	Mean	21.15	Mean	9.36	Mean	16.25
Median	6.32	Median	19	Median	8.6	Median	11.5
Stand. Dev.	0.85	Stand. Dev.	14.91	Stand. Dev.	5.92	Stand. Dev.	16.43
Range	4.98-8.01	Range	1.5-51	Range	<0.5-23.1	Range	5-63
No. of Samples	11	No. of Samples	11	No. of Samples	12	No. of Samples	12

Note: Means, medians, standard deviations and ranges are in mg/L, except for pH.

TABLE 22. DISTRIBUTION OF CSI, SI, LI AND AI VALUES

ROUND 2 - FINISHED GROUNDWATER

CSI	% of Tests	SI	% of Tests	LI	% of Tests	AI	% of Tests
≤1	0	7-8.9	0	≥0	0	≥12	0
1.0-1.9	10	9-10.9	0	0 to -1.9	10	10-11.9	20
2.0-2.9	40	11-12.9	70	-2 to -3.9	60	8-9.9	50
3.0-3.9	20	13-14.9	20	-4 to -5.9	30	6-7.9	30
4.0-4.9	20	15-16.9	10	≤-6	0	≤6	0
≥5	10	≥17	0				
No. of samples	10	No. of samples	10	No. of samples	10	No. of samples	10

TABLE 23. TOXIC ELEMENT DATA - ROUND 2

RAW AND FINISHED SURFACE WATERS

Compound or Element	MCL in mg/L	Number of Tests(N) Surface Raw	Number of Tests(N) Surface Finished	Analytical Range mg/L Surface Raw	Analytical Range mg/L Surface Finished	No. of Tests >MCL Surface Raw	No. of Tests >MCL Surface Finished
Arsenic	0.05	42	33	all=<0.005	<0.005-0.059	0	1
Barium	1	42	33	<0.2-0.22	all=<0.2	0	0
Cadmium	0.010	42	33	<0.002-0.006	<0.002-0.018	0	1
Lead	0.05	42	33	<0.005-0.016	<0.005-0.116	0	1
Mercury	0.002	42	33	<0.0005-0.0036	all=<0.0005	1	0
Selenium	0.01	42	33	all=<0.005	<0.005-0.017	0	1
Aluminum	NONE	42	33	<0.1-0.35	<0.1-0.4	-	-
Nitrate as N	10	42	33	<0.3-3.0	<0.3-3.4	0	0

TABLE 24. TOXIC ELEMENT DATA - ROUND 2

RAW AND FINISHED GROUNDWATERS

Compound or Element	MCL in mg/L	Number of Tests(N) Ground Raw	Ground Finished	Analytical Range mg/L Ground Raw	Ground Finished	No. of Tests >MCL Ground Raw	Ground Finished
Arsenic	0.05	83	12	all=<0.005	<0.005-0.030	0	0
Barium	1	83	12	<0.2-0.23	all=<0.2	0	0
Cadmium	0.010	83	12	<0.002-0.006	<0.002-0.010	0	0
Lead	0.05	83	12	<0.005-0.120	<0.005-0.08	1	1
Mercury	0.002	83	12	<0.0005-0.0011	<0.0005-0.0008	0	0
Selenium	0.01	83	12	<0.005-0.026	all=<0.005	2	0
Aluminum	NONE	83	12	<0.1-0.4	<0.1-0.3	-	-
Nitrate as N	10	83	12	<0.3-11.9	<0.3-2.8	1	0

Data on pH, alkalinity, calcium, and sulfate are given in Tables 25-28. The coastal aquifers, which were sand, had lower pH values and lower concentrations of calcium, sulfate, and alkalinity. The indices of water quality for coastal vs. Appalachian waters are shown in Figure 7. The two groupings appear to differ substantially for each index.

Table 29 gives data on number of tests, analytical ranges and number of tests exceeding EPA MCL's for the heavy metals and nitrate, plus aluminum. The only MCL exceeded was for lead, with one sample well above the 0.05 mg/L level.

TAP WATER QUALITY, ROUNDS 2 AND 3

As part of the work of Rounds 2 and 3 of the project, samples of water were collected from selected premises in some of the water supplies. This was done utilizing a system developed by EPA to simulate by a series of three early morning samples what the quality of the water would have been during an all day use by members of the family, i.e., what quality of water was being ingested. This work was done in the six New England States and New York, Pennsylvania, North Carolina and New Jersey.

Data from the analysis of early morning samples are shown in Table 30. The water that was standing overnight in plumbing had the highest concentration of metals about two-thirds of the time. One fifth of the time the highest metal concentration was found in water that had been at rest overnight in the service line.

A summary of the percentage of samples exceeding the MCL for lead is shown in Table 31. The percentage of samples exceeding the SMCL for copper is shown in Table 32. No samples of water freshly drawn from the distribution system exceeded the MCL for lead, and only one service line sample exceeded the 0.05 mg/L MCL. The SMCL of 1 mg/L for copper was met or exceeded often (42 percent) in household water samples, and 21 percent of the time in service line samples. Copper met or exceeded 1 mg/L in only 5 percent of the distribution system samples, however.

TABLE 25. DISTRIBUTION OF pH

ROUND 3 - GROUNDWATERS

Range Interval pH	Percent of Tests in Range Interval Coastal	Appalachian
4.0-4.9	43	5
5.0-5.9	36	14
6.0-6.9	14	46
7.0-7.9	7	33
8.0-8.9	0	2
Geometric Mean	4.64	5.78
Median	5.44	6.58
Stand. Dev.	0.94	0.83
Range	4.15-7.03	4.67-8.02
No. of Samples	14	57

TABLE 26. DISTRIBUTION OF ALKALINITIES

ROUND 3 - GROUNDWATERS

Range Interval Alkalinity (mg/L as $CaCO_3$)	Percent of Tests in Range Interval	
	Coastal	Appalachian
0-4.9	50	4
5.0-9.9	36	7
10.0-29	7	14
30-49	7	12
50-99	0	19
100-149	0	16
150-199	0	18
200-249	0	3
250-299	0	7
Mean	*10.17	100.14
Median	4.82	86.1
Stand. Dev.	*11.02	79.05
Range	<0.1-36.8	<0.1-284
No. of samples	14	57

*Calculation from 10 samples   4 = <0.1

TABLE 27. DISTRIBUTION OF CALCIUM

ROUND 3 - GROUNDWATERS

Range Interval Calcium (mg/L)	Percent of Tests in Range Interval Coastal	Appalachian
0-4	79	7
5-9	14	14
10-24	7	28
25-49	0	23
50-74	0	18
75-99	0	7
100-124	0	3
Mean	3.09	34.75
Median	1.85	25
Stand. Dev.	3.01	28.71
Range	0.8-11	1.2-124
No. of Samples	14	57

TABLE 28. DISTRIBUTION OF SULFATE

ROUND 3 - GROUNDWATERS

Range Interval Sulfate (mg/L)	Percent of Tests in Range Interval Coastal	Appalachian
0-39	100	72
40-79	0	12
80-119	0	11
120-159	0	3
160-199	0	2
Mean	5.71	32.98
Median	4	14
Stand. Dev.	4.12	42.33
Range	1-16	<1-194
No. of Samples	14	57

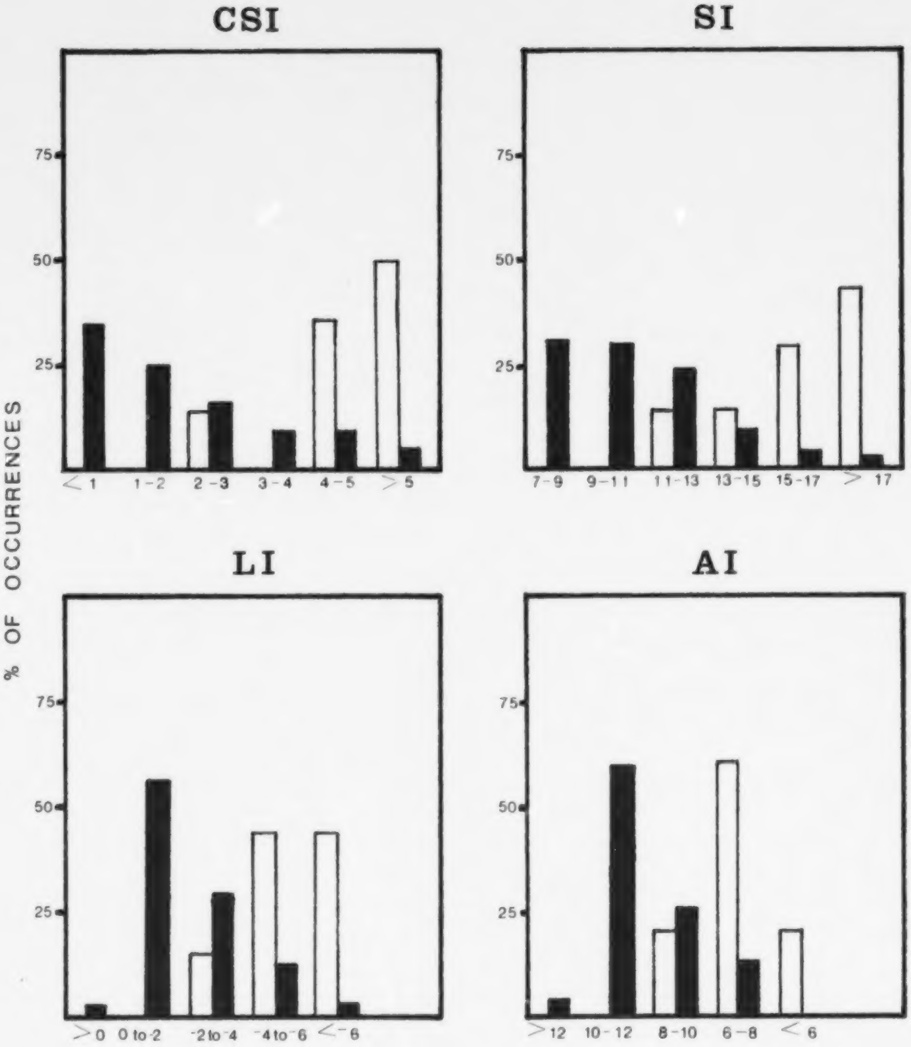


FIGURE 7. COMPARISON OF COASTAL AND APPALACHIAN GROUND WATERS

☐ COASTAL ■ APPALACHIAN

TABLE 29. COMPARISON OF TEST RESULTS

WITH EPA PRIMARY MCL'S FOR HEAVY METALS AND NITRATE

Compound or Element	MCL in mg/L	Number of Tests (N)		Analytical Range (mg/L)		No. of Tests >MCL	
		Coastal	App	Coastal	Appalachian	Coastal	App
Arsenic	0.05	14	57	<0.005(No Range)	<0.005 (N.R.)	0	0
Barium	1	14	57	<0.2 (No Range)	<0.2-0.98	0	0
Cadmium	0.010	14	57	<0.002-0.002	<0.002 (N.R.)	0	0
Lead	0.05	14	57	<0.005-0.033(2.75)*	<0.005-0.46	0	1
Mercury	0.002	14	57	<0.0005 (N.R.)	<0.005-0.001	0	0
Selenium	0.01	14	57	<0.005 (N.R.)	<0.005-0.007	0	0
Aluminum	NONE	14	57	<0.1-0.39	<0.1-0.2	-	-
Nitrate as N	10	14	57	<0.3-3.1	<0.3-5.1	0	0

*This value (2.75) due to a faulty procedure in collecting sample from Martha's Vineyard.

TABLE 30. EARLY MORNING SAMPLES
ROUNDS 2 AND 3 OF NEWWA WATER QUALITY STUDY
METALS CONTENT OF DRINKING WATER

Community	Type of Pipe	Water Source	Sample Source	Metals In Tap Water mg/L						LI
				Cu**	Pb*	Fe**	Cd*	Zn**	Al***	
				Connecticut						
Bristol		S,F	1	<0.02	<0.005	<0.1	<0.002	0.02	0.1	
Bristol		S,F	2	<.02	<.005	<.1	<.002	<.02	.1	-3.02
Bristol		S,F	3	<.02	.006	<.1	<.002	<.02	.1	
Norwich		S,F	1	.33	.007	<.1	<.002	.11	<.1	
Norwich		S,F	2	.24	<.005	<.1	<.002	.05	<.1	-4.00
Norwich		S,F	3	.06	<.005	<.1	<.002	.05	<.1	
Clinton		S,F	1	.19	<.005	<.1	<.002	<.02	<.1	
Clinton		S,F	2	.15	<.005	<.1	<.002	<.02	<.1	-3.05
Clinton		S,F	3	.15	<.005	<.1	<.002	<.02	<.1	
Portland		S,F	1	.46	.007	.29	<.002	.03	<.1	
Portland		S,F	2	.05	<.005	.39	<.002	<.02	.1	-3.06
Portland		S,F	3	.06	.005	.42	<.002	.02	.1	
				Maine						
Stonington-Hancock		S,F	1	2.11	0.104	0.43	<0.002	0.20	<0.1	
Stonington-Hancock		S,F	2	0.05	.005	.92	<.002	.03	<.1	-3.28
Stonington-Hancock		S,F	3	<0.02	.006	.47	<.002	<.02	<.1	
No.Windham-Cumberland		G,F	1	1.63	.010	<.1	<.002	.83	<.1	
No.Windham-Cumberland		G,F	2	0.39	<.005	<.1	<.002	.50	<.1	-2.88
No.Windham-Cumberland		G,F	3	0.19	<.005	<.1	<.002	.44	<.1	
Bath		S,F	1	0.03	.011	.31	<.002	.09	<.1	
Bath		S,F	2	<0.02	<.005	.29	<.002	.06	<.1	-1.33
Bath		S,F	3	<0.02	<.005	.21	<.002	<.02	<.1	
Rangely-Franklin		S,F	1	2.20	.007	.13	<.002	.11	<.1	
Rangely-Franklin		S,F	2	0.51	<.005	.11	<.002	.02	<.1	-4.46
Rangely-Franklin		S,F	3	0.34	.006	.17	<.002	.03	<.1	

TABLE 30. EARLY MORNING SAMPLES - (CONTINUED)
ROUNDS 2 AND 3 OF NEWWA WATER QUALITY STUDY
METALS CONTENT OF DRINKING WATER

Community	Type of Pipe	Water Source	Sample Source	Metals In Tap Water mg/L						LI
				Cu**	Pb*	Fe**	Cd*	Zn**	Al***	
			Massachusetts							
Plymouth	Copper	S,F	1	0.86	0.016	<0.1	<0.002	0.14	<0.1	-5.20
Plymouth	Service-Cast	S,F	2	0.82	<.005	<.1	<.002	<0.02	<.1	
Plymouth	Iron Main	S,F	3	0.39	<.005	<.1	<.002	<0.02	<.1	
Athol-Worcester	Copper Service-	S,F	1	0.20	.052	.27	<.002	0.09	<.1	
Athol-Worcester	Cast Iron Main	S,F	2	0.11	.010	.28	<.002	0.03	<.1	-6.26
Athol-Worcester		S,F	3	0.12	.008	.27	<.002	<0.02	<.1	
Pittsfield-Berkshire	Copper Service-	S,F	1	0.59	.009	.16	<.002	0.14	<.1	
Pittsfield-Berkshire	Cast Iron	S,F	2	0.49	.006	.19	<.002	0.08	<.1	-8.13
Pittsfield-Berkshire	Main	S,F	3	0.51	.005	.14	<.002	0.05	<.1	
W.Boylston-Worcester	Cement Lined	G,F	1	1.64	.014	<.1	<.002	0.75	<.1	-3.19
W. Boylston-Worcester	Iron Service-	G,F	2	0.31	.010	<.1	<.002	<0.02	<.1	
W. Boylston-Worcester	Asbestos Cement Main	G,F	3	0.14	.008	<.1	<.002	<0.02	<.1	
Holden-Worcester	Galv. Iron	G,F	1	1.24	.082	<.1	<.002	0.15	<.1	
Holden-Worcester	Service Pipe-	G,F	2	0.24	.009	<.1	<.002	<0.02	<.1	-4.68
Holden-Worcester	Cast Iron Main	G,F	3	0.08	.006	<.1	<.002	<0.02	<.1	
Fitchburg-Worcester (City Hall)	Copper Service Cast Iron	S,F	1	0.40	.016	.40	.004	2.89	<.1	
Fitchburg-Worcester(C.H.)	Main	S,F	2	0.19	.006	.27	.003	2.72	<.1	-7.59
Fitchburg-Worcester(C.H.)		S,F	3	0.14	.006	.63	<.002	0.39	<.1	
Fitchburg-Worcester(14 Cabot St.)		S,F	1A	1.45	.030	.21	<.002	0.72	<.1	
Fitchburg-Worcester(14 Cabot St.)		S,F	2A	0.38	.042	.24	<.002	0.40	<.1	
Fitchburg-Worcester(14 Cabot St.)		S,F	3A	0.14	.020	.24	<.002	0.27		

TABLE 30. EARLY MORNING SAMPLES - (CONTINUED)
ROUNDS 2 AND 3 OF NEWWA WATER QUALITY STUDY
METALS CONTENT OF DRINKING WATER

Community	Type of Pipe	Water Source	Sample Source	Metals In Tap Water mg/L Cu**	Pb*	Fe**	Cd*	Zn**	Al***	LI
		Massachusetts - (Continued)								
Lancaster-Worcester	Copper Service	G,F	1	1.05	0.082	<0.1	<0.002	0.48	<0.1	
Lancaster-Worcester	Pipe Ductile	G,F	2	1.20	.026	<.1	<.002	0.10	<.1	-3.01
Lancaster-Worcester	Iron Main	G,F	3	0.24	.011	<.1	<.002	0.04	<.1	
Winchendon-Worcester	3/4" Cu. Service-	S,F	1	0.95	.018	.19	<.002	<0.02	<.1	
Winchendon-Worcester	10" Cast	S,F	2	1.62	.008	.12	<.002	0.04	<.1	-5.27
Winchendon-Worcester	Iron Main	S,F	3	1.40	.012	.22	<.002	<0.02	.1	
Leominster-Worcester	3/4" Copper	S,F	1	2.30	.025	<.1	<.002	0.05	.1	
Leominster-Worcester	Service Cast	S,F	2	1.34	.018	<.1	<.002	0.05	<.1	-0.53
Leominster-Worcester	Iron Main	S,F	3	0.42	.006	.25	.004	0.02	.1	
		New Hampshire								
Rochester-Statford		S,F	1	3.18	0.024	0.24	<0.002	0.36	<0.1	
Rochester-Statford		S,F	2	3.51	<.005	.21	<.002	0.07	<.1	-7.65
Rochester-Statford		S,F	3	2.48	.007	.26	<.002	0.03	<.1	
Hudson-Hillsboro	1st use of service	G,F	1	1.02	.016	<.1	<.002	0.49	<.1	
Hudson-Hillsboro	pipe 100 of	G,F	2	0.21	<.005	.12	<.002	0.24	<.1	-3.49
Hudson-Hillsboro	1" Galv. from old	G,F	3	0.07	<.005	.11	<.002	0.14	.1	
C.I. 150'	Pipe on Lovell Rd. service overall.									
Franklin-Merrimack	50' Cu ACME	G,F	1	3.06	1.23	<.1	<.002	0.84	<.1	
Franklin Merrimack	Well No. 1	G,F	2	0.67	.023	.29	<.002	0.11	<.1	-4.33
Franklin-Merrimack		G,F	3	0.19	.017	<.1	<.002	<0.02	<.1	

TABLE 30. EARLY MORNING SAMPLES - (CONTINUED)
ROUNDS 2 AND 3 OF NEWWA WATER QUALITY STUDY
METALS CONTENT OF DRINKING WATER

Community	Type of Pipe	Water Source	Sample Source	Metals In Tap Water mg/L						LI
				Cu**	Pb*	Fe**	Cd*	Zn**	Al***	
New Hampshire - (Continued)										
Keene-Cheshire	Old 4" District	S,F	1	0.10	0.022	5.14	<0.002	1.04	0.1	
Keene-Cheshire	Main	S,F	2	0.03	.010	0.36	<.002	0.05	.1	-8.43
Keene-Cheshire		S,F	3	0.04	<.005	0.12	<.002	0.02	<.1	
Wolfeboro-Carroll	Service Used for	S,F	1	1.05	.025	<0.1	<.002	0.12	<.1	
Wolfeboro-Carroll	Sprinkling, Testing,	S,F	2	1.25	.054	0.99	.003	<0.02	.3	-4.44
Wolfeboro-Carroll	Pressure, Etc.- 15' of Cu. Service.	S,F	3	<0.02	<.005	<0.1	.004	<0.02	<.1	
Georges Mills-Sullivan	Srvc. 40' of	S,F	1	0.65	.006	0.53	.003	0.17	.1	
Georges Mills-Sullivan	3/4 Cu. Dist.Main	S,F	2	1.40	<.005	0.53	<.002	<0.02	<.1	-5.72
Georges Mills-Sullivan	6" 1950 PL	S,F	3	0.16	.006	0.56	<.002	<0.02	.1	
Sunapee-Sullivan	20' of Cu. Srvc.	S,F	1	1.47	.066	0.32	.004	0.05	<.1	
Sunapee-Sullivan	Pipe 6" C.I. Dist.	S,F	2	1.07	.019	1.30	<.002	0.22	<.1	-4.77
Sunapee-Sullivan	Main Laid in 1950.	S,F	3	0.05	.006	0.38	<.002	0.05	<.1	
Hookset-Monicak	Distr. Main	G,F	1	0.06	<.005	<0.1	<.002	0.02	.1	
Hookset-Monicak	Transite (CA.)	G,F	2	0.05	<.005	<0.1	<.002	0.03	.1	-2.12
Hookset-Monicak	Service- 75' Cu.	G,F	3	0.03	<.005	<0.1	<.002	0.03	.1	
Lincoln-Grafton		S,F	1	0.50	.018	<0.1	<.002	0.11	.2	
Lincoln-Grafton		S,F	2	0.09	<.005	0.14	<.002	0.04	.2	-5.49
Lincoln-Grafton		S,F	3	0.06	.005	<0.1	<.002	0.03	.2	
Littleton-Grafton	10" Distr.	S,F	1	1.45	<.005	0.34	<.002	0.19	<.1	
Littleton-Grafton	Main	S,F	2	1.66	<.005	<0.1	<.002	0.03	<.1	-4.37
Littleton-Grafton		S,F	3	0.05	<.005	<0.1	<.002	0.03	.1	

TABLE 30. EARLY MORNING SAMPLES - (CONTINUED)
ROUNDS 2 AND 3 OF NEWWA WATER QUALITY STUDY
METALS CONTENT OF DRINKING WATER

Community	Type of Pipe	Water Source	Sample Source	Metals In Tap Water mg/L						LI
				Cu**	Pb*	Fe**	Cd*	Zn**	Al***	
				Rhode Island						
Scituate		S,F	1	0.21	<0.005	<0.1	<0.002	0.05	<0.1	0.19
Scituate		S,F	2	.04	<.005	<.1	<.002	<.02	.1	
Scituate		S,F	3	<.02	<.005	.11	<.002	<.02	.1	
				Vermont						
Cavendish		G,F	1	1.68	<0.005	0.10	<0.002	0.55	<0.1	-2.42
Cavendish		G,F	2	0.99	.009	<.1	<.002	.07	<.1	
Cavendish		G,F	3	0.16	.005	.13	<.002	<.02	<.1	
Bakersfield	Galv. Iron & Copper Supply Pipe	G,F	1	0.44	<.005	<.1	<.002	.24	<.1	-.544
Bakersfield		G,F	2	0.16	<.005	<.1	<.002	<.02	<.1	
Bakersfield		G,F	3	0.04	.030	<.1	<.002	<.02	<.1	
				New York						
Saranac		S,F	1	1.61	0.022	<0.1	<0.002	0.26	<0.1	-4.48
Saranac		S,F	2	0.48	.006	<.1	<.002	.07	.1	
Saranac		S,F	3	0.19	.006	<.1	<.002	.08	<.1	
Tupper Lk-Franklin		S,F	1	0.47	.006	.27	<.002	.44	.2	-7.42
Tupper Lk-Franklin		S,F	2	0.07	<.005	.21	<.002	.39	.2	
Tupper Lk-Franklin		S,F	3	0.05	.005	.23	<.002	.40	.2	
Long Lk-Hamilton		S,F	1	0.95	.006	<.1	.003	.04	.1	-4.32
Long Lk-Hamilton		S,F	2	0.64	.007	.11	.006	.02	.1	
Long Lk-Hamilton		S,F	3	0.13	<.005	<.1	<.002	<.02	<.1	
Old Forge-Herkimer		S,F	1	2.71	.015	<.1	<.002	.13	<.1	-6.22
Old Forge-Herkimer		S,F	2	3.04	<.005	<.1	<.002	.03	.1	
Old Forge-Herkimer		S,F	3	0.49	<.005	<.1	<.002	<.02	.1	
Covewood Lodge		G,R	1	0.22	.016	.16	<.002	.10	<.1	* -2.81
Covewood Lodge		G,R	2	<0.02	<.005	.10	<.002	<.02	<.1	
Covewood Lodge		G,R	3	0.05	<.005	.13	<.002	<.02	<.1	

*These LI are taken from Round 1 because none were available on Round 2.

TABLE 30. EARLY MORNING SAMPLES - (CONTINUED)
ROUNDS 2 AND 3 OF NEWWA WATER QUALITY STUDY
METALS CONTENT OF DRINKING WATER

Community	Type of Pipe	Water Source	Sample Source	Metals In Tap Water mg/L						LI
				Cu**	Pb*	Fe**	Cd*	Zn**	Al***	
				Pennsylvania						
Millersburg		F,G	1	0.25	0.012	<0.1	<0.002	4.16	<0.1	
Millersburg		F,G	2	.07	.01	.29	<.002	0.05	<.1	-2.53
Millersburg		F,G	3	.03	.005	.5	<.002	0.04	<.1	
Dallas		F,G	1	.22	.009	.11	<.002	0.82	<.1	
Dallas		F,G	2	.2	.006	<.1	<.002	0.04	<.1	-2.14
Dallas		F,G	3	.04	<.005	<.1	<.002	<0.02	<.1	
				New Jersey						
Lakehurst		F,G	1	0.04	0.037	0.19	<0.002	<0.02	0.1	
Lakehurst		F,G	2	<.02	.007	.19	<.002	<.02	.1	-6.51
Lakehurst		F,G	3	<.02	.006	.37	<.002	<.02	.1	
Barnegat		F,G	1	.02	<.005	.2	<.002	<.02	<.1	
Barnegat		F,G	2	<.02	<.005	.11	<.002	<.02	<.1	-9.31
Barnega		F,G	3	<.02	<.005	.15	<.002	<.02	<.1	
				North Carolina						
Marble Comm	Distr.	O,G	1	<0.02	<0.005	0.36	<0.002	0.07	<0.1	
Marble Comm.	Sys.	O,G	2	<0.02	<.005	.46	<.002	.05	<.1	-5.88
Marble Comm.	A.C.	O,G	3	0.02	<.005	.15	<.002	.31	<.1	
Newland	Copper	F,G	1	0.12	<.005	<.1	<.002	<.02	<.1	
Newland	Plumbing	F,G	2	0.06	<.005	<.1	<.002	<.02	<.1	-4.49
Newland	Chlorination	F,G	3	0.02	<.005	<.1	<.002	<.02	<.1	
West Jefferson	Copper	P,G	1	1.67	.006	<.1	<.002	.67	<.1	
West Jefferson	Plumbing Chlorin.	P,G	2	0.07	<.005	<.1	<.002	.55	<.1	-2.82
West Jefferson		P,G	3	0.05	<.005	<.1	<.002	.47	<.1	

Water Source Key:
S Surface
G Ground
F Finished
R Raw
P Partial

Sample Source Key:
1. Standing overnight in plumbing
2. Service Line
3. Water Main

*EPA Primary MCL's Pb 0.05 mg/L
Cd 0.010 mg/L
**EPA Secondary MCL's Cu 1 mg/L
Fe 0.03 mg/L
Zn 5 mg/L
***ANSI Standard for Kidney dialysis water Al 0.010 mg/L

TABLE 31. ROUND 2 AND 3 - NEWWA WATER QUALITY STUDY EARLY MORNING SAMPLES SAMPLES EQUAL TO OR EXCEEDING MCL FOR LEAD**

State	No. of Samples (1's,2's,3's)*	Percent Equal To or Exceeding MCL for Lead			
		1's	2's	3's	All
Connecticut	4	0	0	0	0
Maine	4	25	0	0	8
Massachusetts	10	30	0	0	10
New Hampshire	10	20	10	0	10
New York	5	0	0	0	0
Rhode Island	1	0	0	0	0
Vermont	2	0	0	0	0
Pennsylvania	2	0	0	0	0
New Jersey	2	0	0	0	0
North Carolina	3	0	0	0	0
All	43	14	2	0	6

*Sample Source Key:
1. Standing Overnight in Plumbing
2. Service Line
3. Water Main

**0.05 mg/L

TABLE 32. ROUND 2 AND 3 - NEWWA WATER QUALITY STUDY
EARLY MORNING SAMPLES
SAMPLES EQUAL TO OR EXCEEDING SMCL FOR COPPER**

State	No. of Samples (1's,2's,3's)*	Percent Equal To or Exceeding SMCL for Copper 1's	2's	3's	All
Connecticut	4	0	0	0	0
Maine	4	75	0	0	25
Massachusetts	10	50	30	10	30
New Hampshire	10	60	50	10	40
New York	5	40	20	0	20
Rhode Island	1	0	0	0	0
Vermont	2	50	0	0	17
Pennsylvania	2	0	0	0	0
New Jersey	2	0	0	0	0
North Carolina	3	33	0	0	11
All	43	42	21	5	23

*Sample Source Key:
1. Standing Overnight in Plumbing
2. Service Line
3. Water Main

**1 mg/L Secondary MCL (EPA)

SECTION 8

HISTORICAL RECORDS

SOURCES OF DATA

Historical records were obtained by several of the field investigators and by the NEWWA staff. These varied in completeness and in duration of compilation from a few tests over a period of a few years to extensive analyses for nearly 100 years. The latter were the records of the Lawrence Experiment Station (LES) described in Section 6.

The records of the Lawrence Experimentation Station are considered by the authors to be the best available for New England water. The emphasis on documentation of quality control and quality assurance procedures has increased in recent years, so few, if any, historical records would have the level of QC/QA documentation that is considered necessary today. Evidence was found, however, that indicates that a concern existed for QC/QA throughout the years at the Lawrence Experiment Station. Additional indirect evidence for the high quality of work done at Lawrence was the strong influence of the LES on the first edition of Standard Methods (31). After the first edition of Standard Methods, scientists at LES continued to be involved in revising existing methods and developing new ones. This background information provides strong, although indirect, evidence of the high standards of the Lawrence Experiment Station. Additional evidence of interest in quality control at Lawrence is the Experiment Station's participation in the Analytical Reference Service (ARS) testing program. The U.S. Public Heath Service conducted this program of analysis of unknown solutions. Test solutions were mailed to laboratories where they were analyzed. The results were mailed back to the ARS, which published reports of the results. The LES participated in a 1971 study that included measurement of pH and alkalinity (36).

Another factor that helped to improve the quality of the LES data was the sample collection procedure. According to two present-day staff members (one with 37 years of experience and the other with 25 years), samples were carefull collected, and a sampling protocol was followed. In addition, over the years samples were collected at the same location when possible (in absence of new construction, etc.) and by the same sample collectors for extended periods of time.

The quality of data available at the Providence, Rhode Island, Water Supply Board was also a known factor. In this case, the chemist of the Water Supply Board, who retired after a career of 38 years, was the Rhode

Island field representative for this research project. For this study, Mr. Collins was able to draw upon his years of experience and provide information about analytical work conducted during his tenure.

HISTORICAL DATA

The largest water source for which data were obtained in this study is Quabbin Reservoir, which serves about two million people in the Greater Boston area. It holds 412 billion gallons. Another large reservoir for which data were available is the Cobble Mountain Reservoir, a part of the water system at Springfield, Massachusetts. The capacity of Cobble Mountain Reservoir is 65 billion gallons. Data for a time span of over four decades were also found for Scituate Reservoir, which serves Providence, Rhode Island. Available data for pH, alkalinity, calcium and sulfate are presented in figures and tables in this portion of the report.

Values for alkalinity, pH, and calculated or measured calcium for Quabbin Reservoir as sampled and measured at the entrance to the Quabbin Aquaduct are given in Table 33. Figure 8 shows the trend of alkalinity concentrations from the early 1940's to 1980. The slope of the line of the least squares fit is different from zero, with statistical significance at the 0.0005 level. The trend of pH vs. time is shown in Figure 9. The hypothesis that the slope of the line of the least squares fit is statistically not different from zero can not be rejected at the 0.05 level. Sulfate concentration vs. time is plotted in Figure 10. No analysis for statistical significance was performed on the sulfate data.

Figures 11 and 12 show the variation of alkalinity and pH with time at Cobble Mountain Reservoir. Maximum depth of this impoundment is about 220 feet. The intake serving the filtration plant is 135 feet deep. Thus local surface conditions would not be reflected in these water quality data. Over the past 40 years, alkalinity declined slightly, whereas pH increased. Both slopes are significant at the 0.05 level.

Scituate Reservoir data for pH and alkalinity are shown in Table 34 and Figures 13 and 14. This reservoir, holding 22 billion gallons, was sampled at the surface near the dam spillway. Both pH and alkalinity declined over the past four decades. The scatter in the pH data is less than in the alkalinity data. The least squares fit of the pH data had a slope statistically different from zero at the 0.0001 level. The fit for alkalinity was statistically different from zero at the 0.05 level.

Alkalinity trends for 32 other water sources in Massachusetts are presented in Appendix III. The summary of statistical testing is shown in Table 35. Of the 34 sources, including Cobble Mountain Reservoir and Quabbin Reservoir, 20 had slopes statistically significant at the 0.05 level. Of the 20, 18 had declining trends in alkalinity, and two had increasing trends.

Volume II, Appendix, will contain additional historical water quality data, information on watersheds and aquifers, and analysis of trends.

TABLE 33. WATER QUALITY DATA - QUABBIN RESERVOIR
BOSTON METROPOLITAN DISTRICT, MASSACHUSETTS
1944 - 1980

Year	Alkalinity (mg/L as $CaCO_3$)	pH	Corrected pH	Hardness (mg/L)	Calculated Calcium (mg/L)	Actual Ca*	CSI	LI
1944	11	6.6	6.5	12	3.5		3.48	-3.25
1945	10	6.3	6.2	9	2.6		3.95	-3.71
1946	13	6.8	6.7	19	5.5		3.00	-2.78
1947	10	6.8	6.7	14	4.1		3.25	-3.02
1948	9	6.7	6.5	14	4.1		3.49	-3.27
1949	9	6.7	6.5	10	2.9		3.64	-3.41
1952	7	6.5	6.3	9	2.6		4.00	-3.77
1953	6	6.8		13	3.8		3.40	-3.18
1955	4	6.4		11	3.2		4.05	-3.83
1956	5	6.6		10	2.9		3.80	-3.57
1957	3	6.8		10	2.9		3.82	-3.59
1961	3	6.6		11	3.2		3.98	-3.75
1962	3	6.3		19	5.5		4.04	-3.81
1963	4	6.4		35	10.1		3.55	-3.32
1964	4	6.8		11	3.2		3.65	-3.43
1965	5	6.5		12	3.5		3.82	-3.59
1966	4	6.4		19	5.5		3.84	-3.62
1967	2	6.6		16	4.6		3.99	-3.75
1968	4	6.1		10	2.9		4.40	-4.17
1969	4	6.6		13	3.8		3.78	-3.55
1970	9	6.8		18	5.2		3.08	-2.86
1971	3	6.4		14	4.1		4.07	-2.85
1973	8	7.2		9	2.7	2.6	3.04	-2.81
1974	7	7.0		10	2.9	2.9	3.25	-3.02
1975	6	6.9		9	2.6	2.7	3.45	-3.22
1976	4	6.6		8	2.3	2.3	4.00	-3.77
1977	2	6.8		9	2.6	2.8	4.01	-3.78
1979	2	6.0		9	2.6	2.6	4.85	-3.62
1980	6	7.0		8	2.3	2.4	3.40	-3.17

Alkalinity
y = 8.92
slope = -0.16
r = -0.61

pH
y = 6.47
slope = 0.006
r = 0.25

Hardness
y = 14.14
slope = -0.07
r = -0.14

Calcium
y = 4.09
slope = -0.02
r = -0.13

CSI
y = 3.31
slope = 0.008
r = 0.224

LI
y = -3.31
slope = -0.008
r = -0.224

*Note: Years 1971 through 1980 given to show agreement between calculated and actual calcium values.

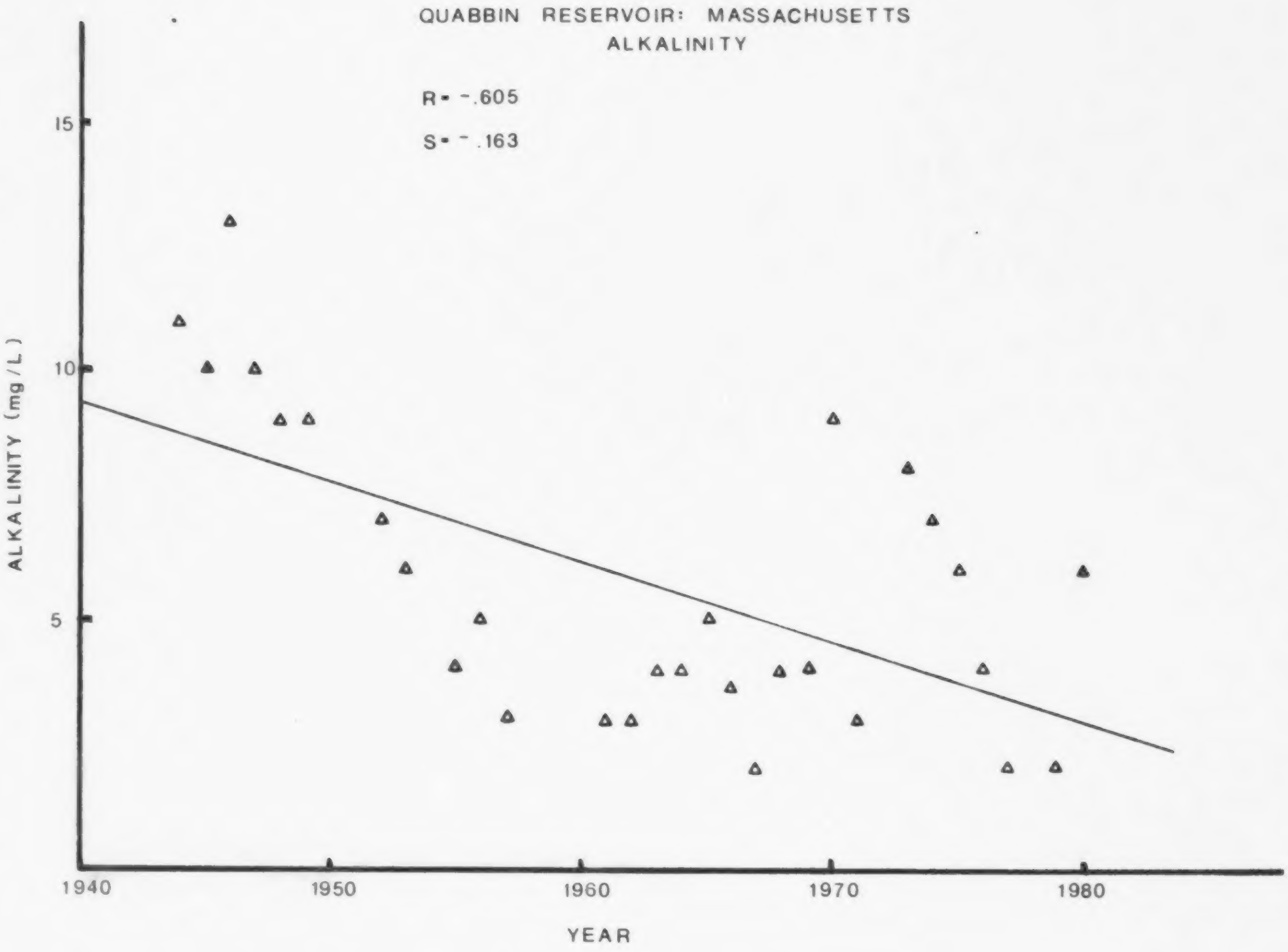


Figure 8. Quabbin Reservoir, MA - Alkalinity as $CaCO_3$

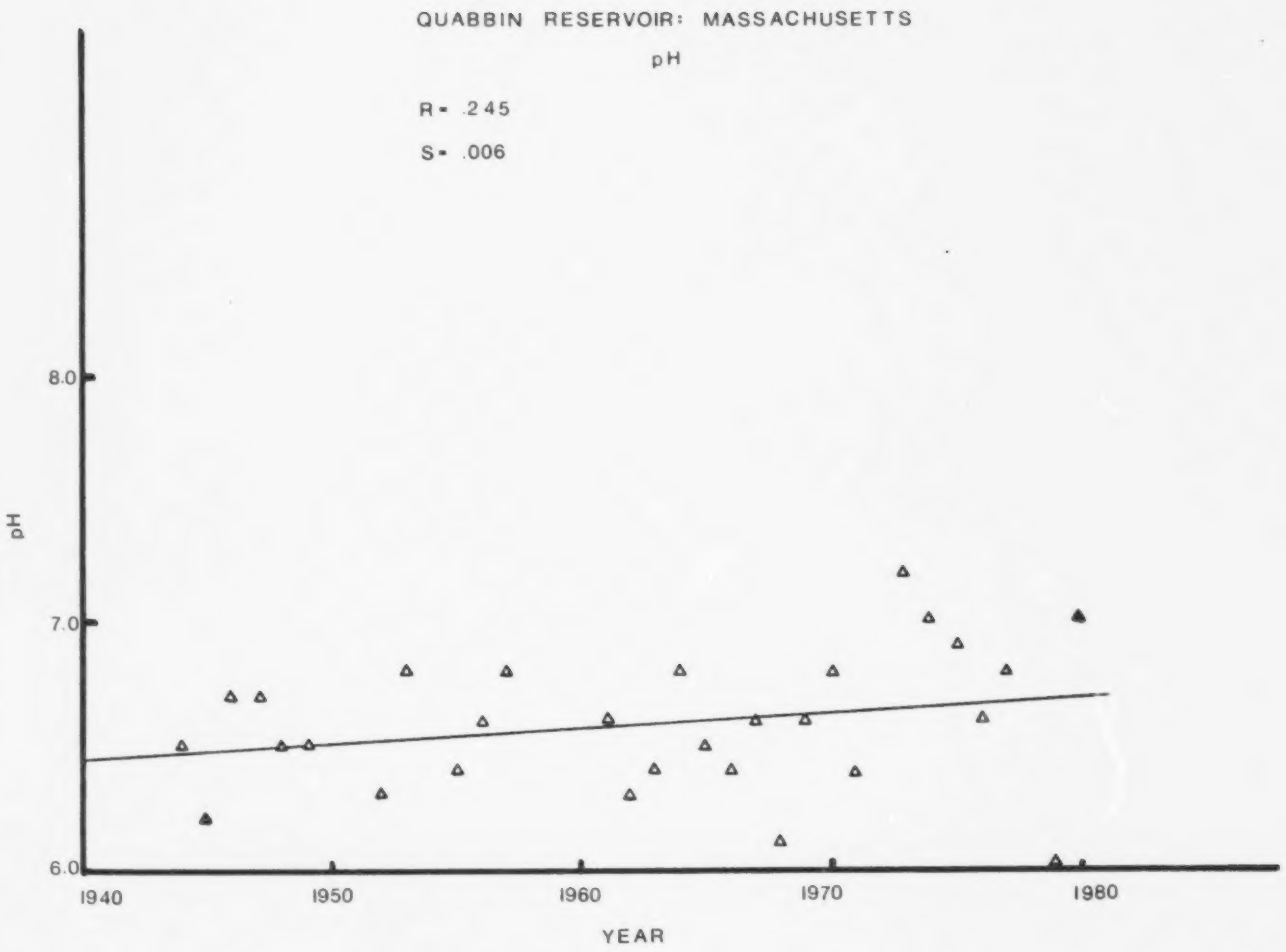


Figure 9. Quabbin Reservoir, MA - pH

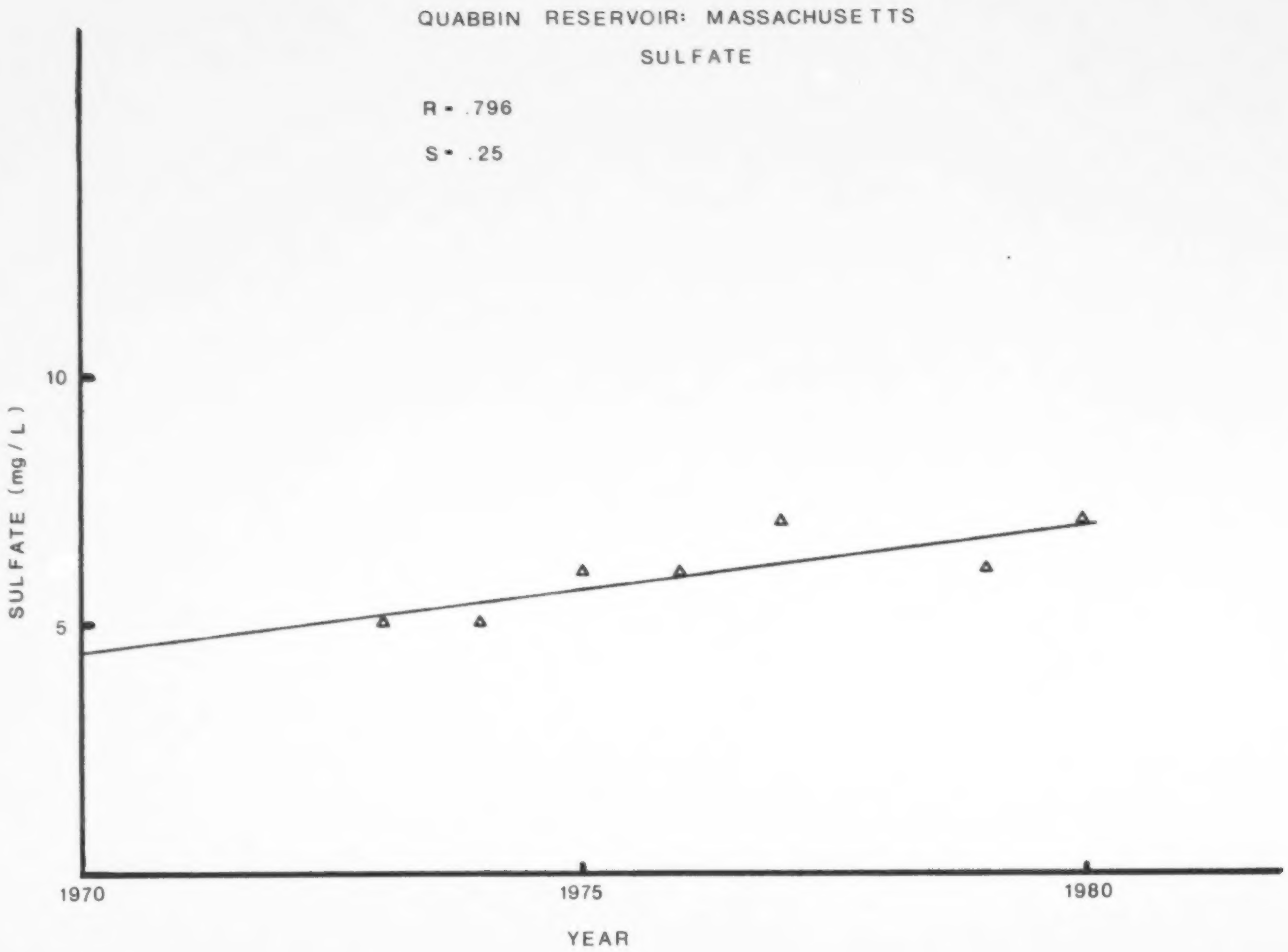


Figure 10. Quabbin Reservoir, MA - Sulfate

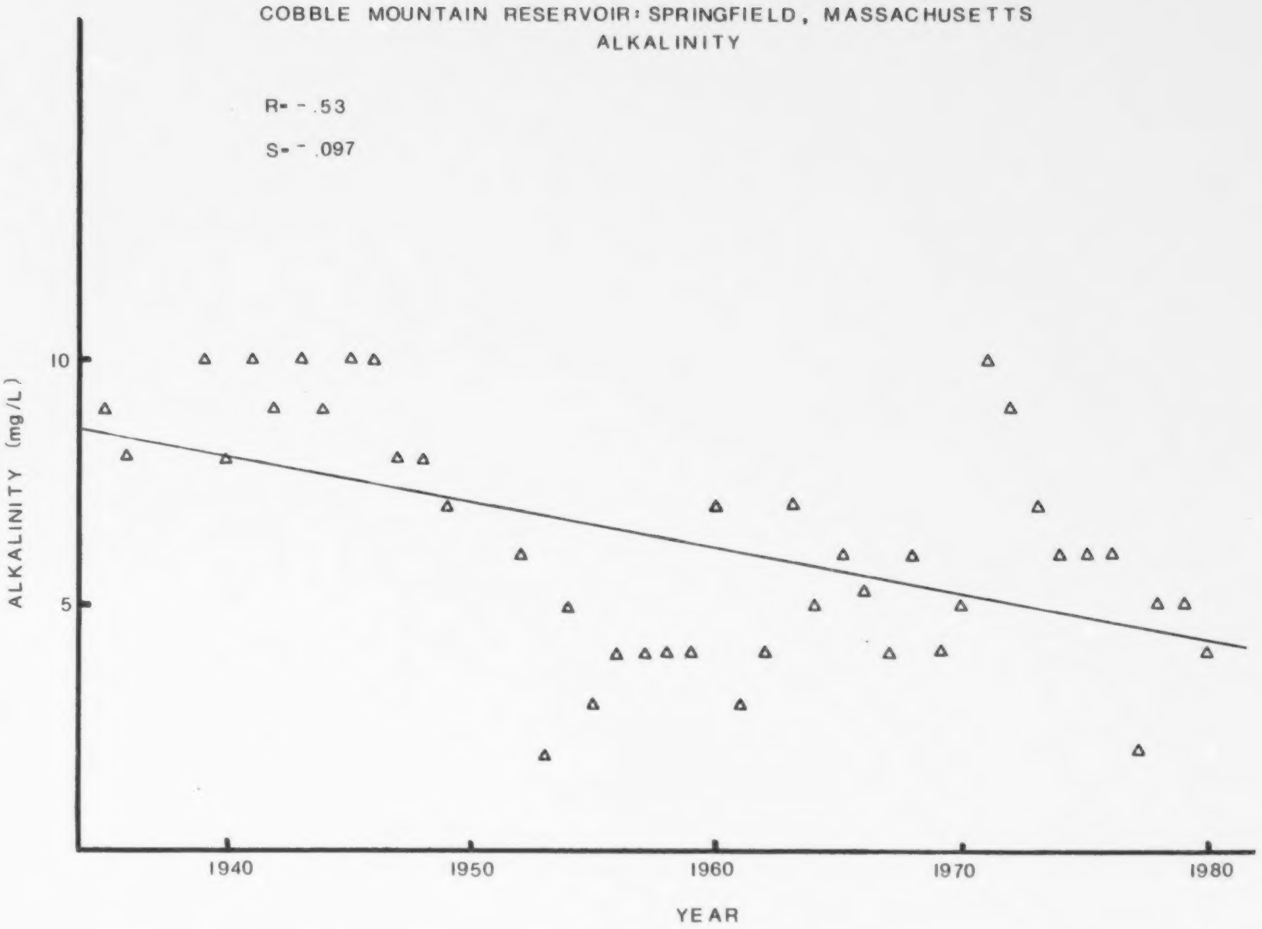


Figure 11. Cobble Mountain Reservoir, MA - Alkalinity as $CaCO_3$

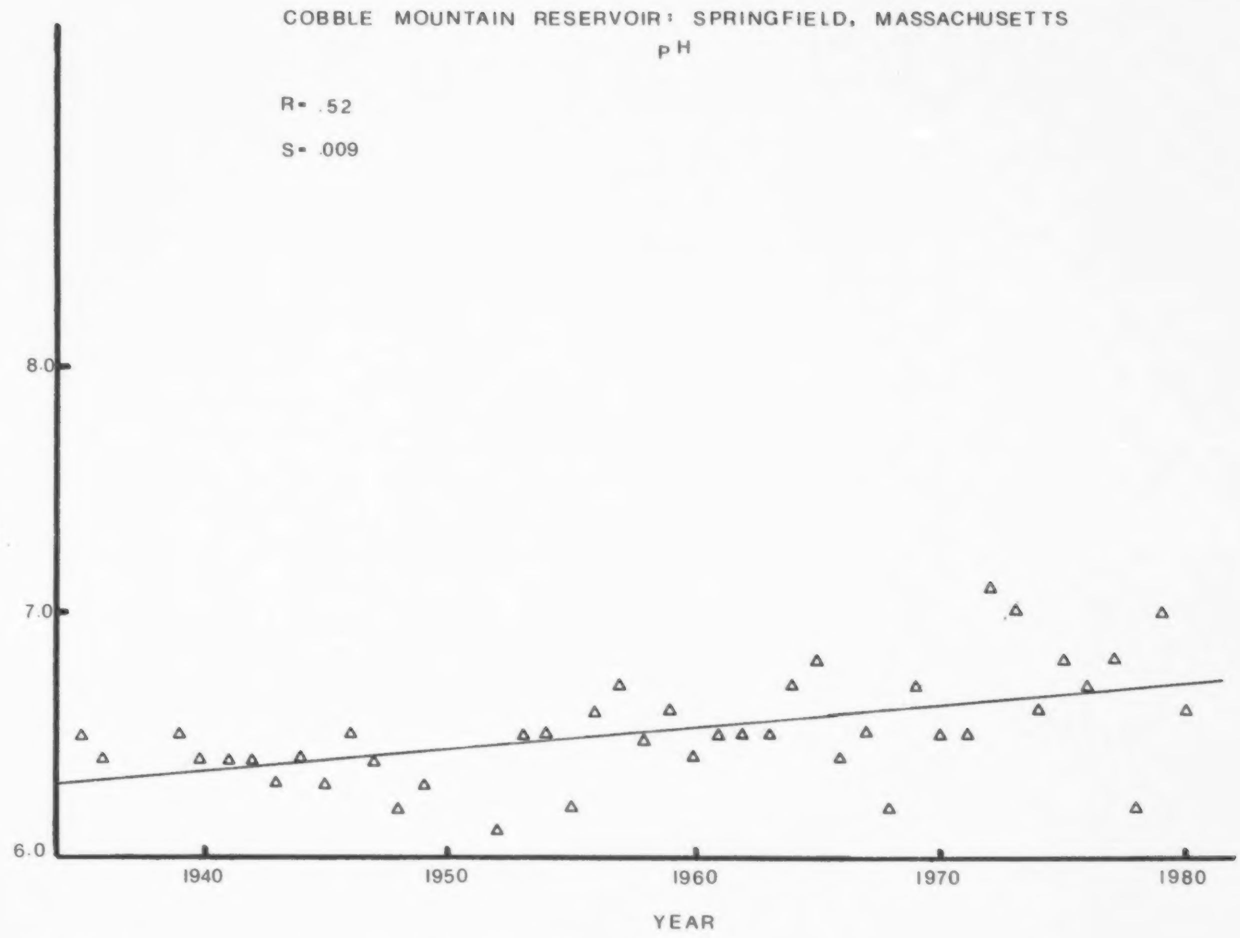


Figure 12. Cobble Mountain Reservoir, MA - pH

TABLE 34. ALKALINITY AND pH VALUES
SCITUATE RESERVOIR, RHODE ISLAND
1937 - 1981

Year	pH	Alkalinity (mg/L as $CaCO_3$)*	Year	pH	Alkalinity (mg/L as $CaCO_3$)*
1937	6.89	4.03	1959	6.59	3.13
1938	6.86	3.00	1960	6.70	3.64
1939	6.88	3.19	1961	6.71	3.51
1940	6.92	2.48	1962	6.55	3.55
1941	6.94	3.15	1963	6.61	4.04
1942	7.18	2.44	1964	6.50	2.68
1943	6.44	3.65	1965	6.43	2.80
1944	6.79	3.40	1966	6.41	2.47
1945	6.41	2.81	1967	6.22	2.03
1946	6.48	2.78	1968	6.29	2.16
1947	6.58	2.51	1969	6.30	2.07
1948	6.48	3.28	1970	6.10	1.98
1949	6.43	3.82	1971	6.20	2.16
1950	6.55	3.86	1972	6.13	2.14
1951	6.57	3.57	1973	6.12	2.14
1952	6.32	3.98	1974	6.40	3.66
1953	6.32	3.84	1975	6.29	3.64
1954	6.44	3.33	1976	6.31	3.19
1955	6.33	3.04	1977	6.38	3.09
1956	6.29	2.97	1978	6.32	2.92
1957	6.71	2.99	1979	6.27	2.22
1958	6.57	2.72	1980	6.44	2.41
			1981	6.60	3.42

*Corrected according to Kramer (1981)

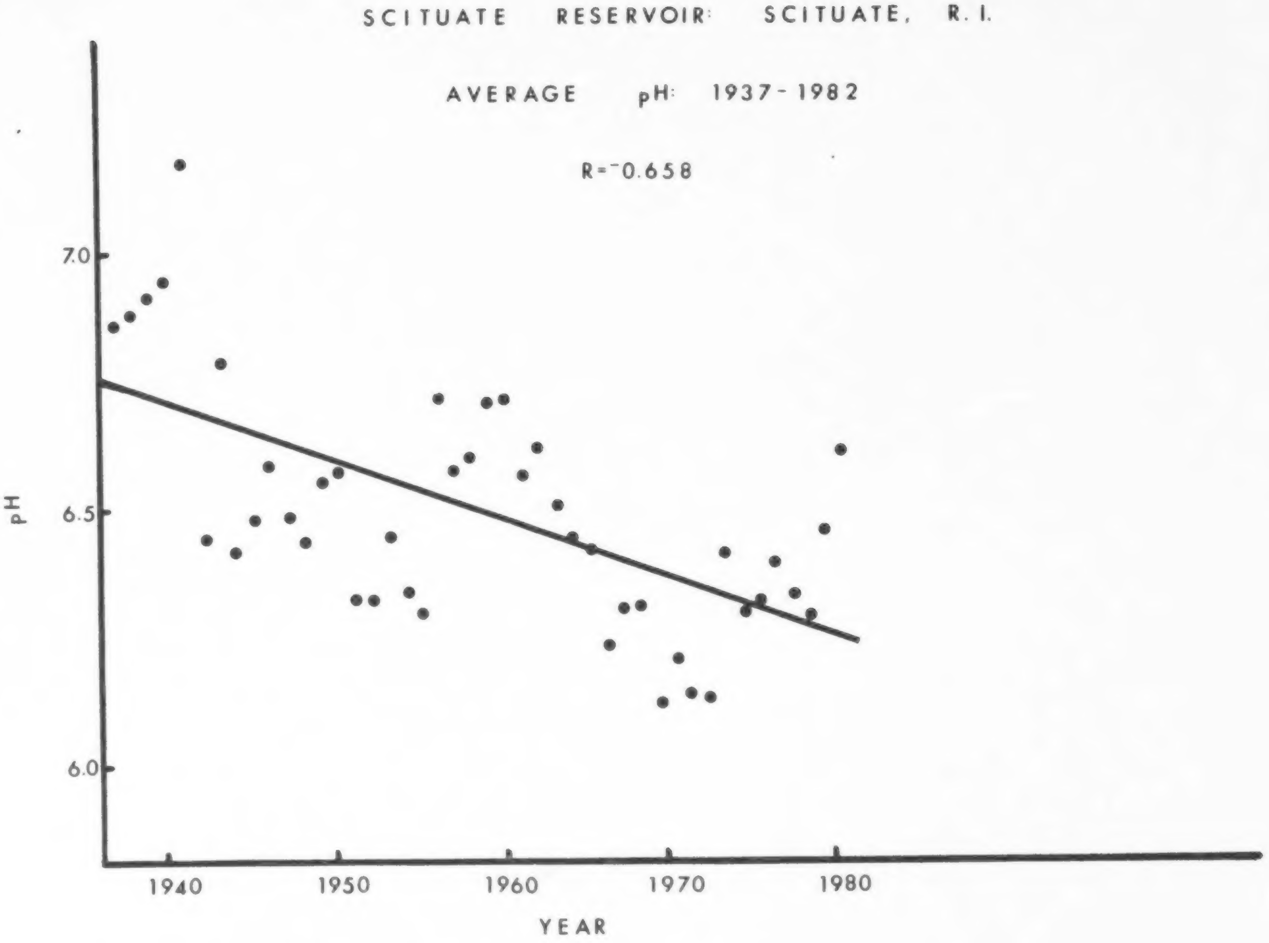


Figure 13. Scituate Reservoir, RI - Average pH

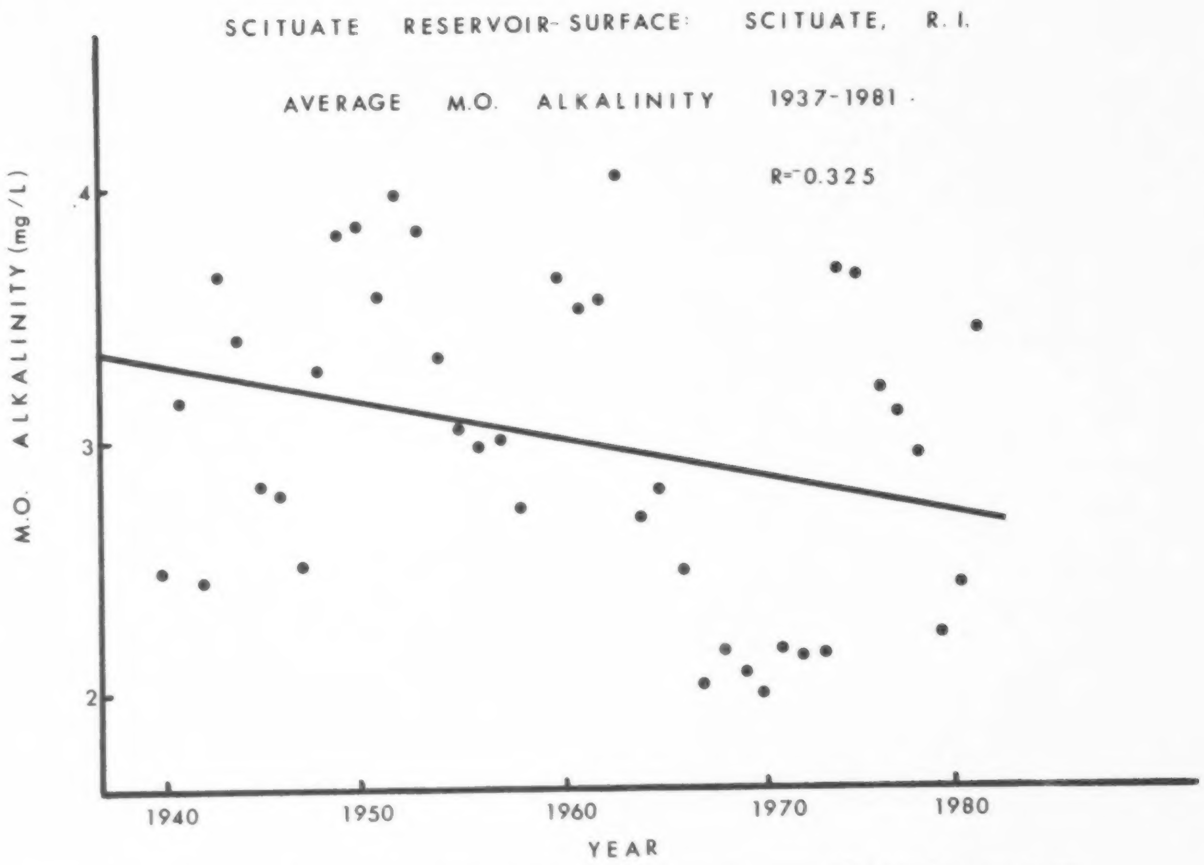


Figure 14. Scituate Reservoir, RI - Average Methyl Orange Alkalinity as $CaCO_3$

TABLE 35. ALKALINITY TRENDS OF RAW WATERS IN MASSACHUSETTS

Community and Water Source	Data Available	Slope Statistically Different From Zero (0.05 level)	Trend in Alkalinity
Springfield-Cobble Mt. Res.	1935-1980	Yes	Down
Athol-Phillipston Reservoir	1935-1981	Yes	Up
Hinsdale-Belmont Reservoir	1935-1980	No	--
Leominster-Fall Brook Res.	1935-1980	No	--
Holyoke-Carmody Reservoir	1935-1980	Yes	Down
Montagoe-Lake Pleasant Res.	1935-1980	Yes	Down
Lee-Upper Codding Brook	1935-1980	No	--
Lakeville-Assawompsett Pond	1935-1980	No	--
Gloucester-Dikes Brook	1935-1980	Yes	Down
Gloucester-Haskell Res.	1935-1980	No	--
Falmouth-Long Pond Res.	1935-1978	No	--
Fall River-North Watuppa Pond	1935-1980	No	--
Dalton-Egypt Brook	1935-1980	Yes	Down
Spencer-Shaw Pond	1935-1980	Yes	Down
Fitchburg-Lovell Reservoir	1935-1980	Yes	Down
Fitchburg-Falulah Brook	1952-1980	Yes	Up
Fitchburg-Mare Meadow	1955-1980	No	--
Westfield-Montgomery	1935-1973	Yes	Down
Winchendon-Old Well	1935-1980	No	--
Winchendon-New Well	1935-1980	No	--
Winchendon-Upper Naukeag Pond	1935-1980	Yes	Down
Southbridge-Hatchett Brook	1935-1980	Yes	Down
Gardner-Crystal Lake	1935-1980	Yes	Down
Worcester-Pine Hill Reservoir	1934-1979	Yes	Down
Salem Beverly-Wenham Lake	1935-1980	No	--
Salem Beverly-Longham Res.	1935-1980	No	--
Plymouth-Great South Pond	1935-1980	Yes	Down
Northampton-Roberts Meadow Br.	1935-1980	Yes	Down
Pittsfield-Farmham Reservoir	1935-1980	Yes	Down
New Bedford-Little Quittacas Pd	1935-1980	Yes	Down
Wachusset Res. at surface	1935-1980	No	--
Wachusset Res. below surface*	1935-1981	Yes	Down
Cambridge-Upper Hoffs Res.	1935-1980	No	--
Boston-Quabbin Reservoir	1944-1980	Yes	Down

*Sampled at 55 ft depth or 90 ft depth

SECTION 9

DISCUSSION

The possible effect of acid rain on community water supplies should be assessed from the perspective of the water supply industry. One key consideration is whether acidic deposition has brought the quality of the raw water out of compliance with drinking water regulations for certain metals that cannot be removed easily. Another is whether the raw water quality is of corrosive nature or capable of depositing calcium carbonate on the inside of the distribution system. The results of this study therefore will be discussed in terms of the EPA Drinking Water Regulations, and in terms of indices which are useful in evaluating the aggressive nature of water and the ability of watersheds or aquifers to handle acidic depostion.

OBSERVED WATER QUALITY VS. QUALITY STANDARDS

Quality standards for public drinking water have been established by EPA. The Primary Drinking Water Regulations (8) defined a "community water system" as ".... a public water system which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents." The regulations apply to community water systems, and portions of the regulations are applied to public water systems not meeting the definition of a community water system. "Appendix A, Background Used in Developing the National Interim Primary Drinking Water Regulations" is contained in the regulations document (8). This appendix sets forth the basis for the drinking water quality standards that were established. Because these health-based standards have already been established through the regulatory process, they are used as the bench mark against which drinking water quality is compared in this report.

Two other quality standards are also used as references. The Secondary Maximum Contaminant Levels were established by EPA through the regulatory process (10), but these are not mandatory nationally. The standard for aluminum set forth by the American National Standards Institute is for dialysis water, not for drinking water. Aluminum in water has been implicated in health problems of some kidney dialysis patients, but this is a small group of more suspectible persons, and the level of aluminum harmful to this group may or may not harm the general public. Although the applicability of the 0.01 mg/L limit for aluminum in water is limited to a small group, data on aluminum are evaluated in the context of this limit.

Quality of raw waters can be evaluated based upon Tables 11, 12, 23, 24 and 29. Cadmium concentration was always below the 0.010 mg/L MCL in 162 raw surface water samples and in 166 raw ground water supplies. The

0.05 mg/L MCL for lead was never equalled or exceeded in 161 raw surface water samples. It was equalled or exceeded twice in 166 raw ground water supplies. The 0.002 mg/L MCL for mercury was equalled or exceeded two times in 162 raw surface water supplies but no times in 166 raw ground waters. On the basis of the samples collected and analyzed, very few potential health problems were found in raw waters.

In a similar fashion, quality of treated waters can be evaluated, using tables 11, 12, 23 and 24. Treated surface waters equalled or exceeded the cadmium MCL one time in 134 samples. In these, waters the MCL for lead was equalled or exceeded two times in 134 samples, whereas the mercury concentration was always below the MCL in 134 samples. Twenty-two samples of treated ground water were analyzed. No sample exceeded the MCL for cadmium or mercury. Only one sample of 22 exceeded the 0.05 mg/L MCL for lead. As with untreated waters, very few potential health problems were found.

Detailed information on the quality of tap waters was presented in Table 30, with data for lead and copper summarized in Tables 31 and 32. In the tap water samples, the cadmium MCL of 0.010 mg/L was never exceeded in 129 samples. The zinc SMCL of 5 mg/L was never exceeded.

The 0.05 mg/L for lead was equalled or exceeded 7 times in 129 samples. This occurred primarily in water that had been standing in household plumbing overnight. Sources of lead in tap water could include lead service lines, lead household piping, and lead used to solder copper pipes and fittings.

The 1 mg/L SMCL for copper was equalled or exceeded (Table 32) by 42 percent of household plumbing samples and 21 percent of service line samples. Likely sources for copper would be copper service lines and copper piping in households.

The results of the tap water sampling program strongly suggest that corrosion was occurring in service lines or household plumbing or both. In a study of the Seattle Water Department's Tolt River supply, EPA (37) concluded that increases of iron, copper, zinc, lead, and cadmium in standing water vs. raw water confirmed the corrosiveness of the Tolt water.

The Seattle Water Department sponsored an investigation of corrosion caused by the Cedar River supply and the Tolt River supply. Corrosion rates were measured for copper piping and galvanized steel piping (38) under existing water quality conditions. Corrosion rates were also measured for various corrosion control strategies involving modification of water quality. Ryder (39) summarized the economic aspects of this study, and showed that the savings associated with longer plumbing life that would be expected as a result of corrosion control would exceed the costs of a corrosion control program by about 5:1.

The capability of water quality modification to reduce corrosion and decrease concentrations of lead in drinking water was shown by Karalekas, Ryan, and Taylor (40) for the water supply of metropolitan Boston and by Schock and Gardels (41) in laboratory research. On the basis of the above results, properly designed corrosion control strategies would be expected to reduce the copper and lead concentrations in the household water samples in this study.

At the end of 1983, EPA had not set an MCL for aluminum. This element had not been implicated in waterborne illness through ingestion, but data showed that aluminum may be hazardous to patients using kidney dialysis. The American National Standards Institute (ANSI) established a limit of 0.01 mg/L for aluminum content of dialysates (13). One outbreak of dialysis encephalopathy has been documented in which the dialysate contained 200 ug/L of aluminum (11). Fifty-five of 162 Round 1 and 2 raw surface water samples contained aluminum equal to or in excess of 0.1 mg/L and 20 showed aluminum equal to or greater than 0.2 mg/L. In Rounds 1, 2 and 3 twenty-four of 166 samples of raw groundwater equalled or exceeded 0.1 mg/L.

Miller et al. (42) published results of a survey of the aluminum content of raw water and treated drinking water in the United States. About half of all raw water samples analyzed exceeded 0.014 mg/L aluminum. This occurred in about 60 percent of the raw surface waters but in about 15 percent of the raw groundwater samples. Aluminum thus is found in raw water sources throughout the United States, and in many cases exceeds 0.01 mg/L.

Data showing concentrations of aluminum and alkalinity as well as pH in water samples from Rounds 1 and 2 are shown in Tables 36-40. Although the solubility of aluminum is a function of pH, no strong relationship of this sort was seen in these data. This could be due to a number of factors not evaluated, including bedrock geology, soil type, and human activity in the watersheds, and presence of suspended aluminum in the water.

QUALITY INDICES

The Langelier Index (LI) and Ryznar's stability index (SI) have been used by persons attempting to estimate the tendency of waters to be corrosive. Ryznar's index was related to actual field observations. Both are based upon calcium carbonate stability, and the indices are similar, as noted by EPA in the Federal Register (16) when the corrosion regulation was published. The similarity of results of these two indices is shown in a plot of LI values vs. SI values for Phillipston Reservoir (Fig. 15).

Data on indices related to corrosion tendencies and on the Calcite Staturation Index were presented in Figures 3-7 and Table 22. The data on quality indices for raw water supplies in Rounds 1 and 2 are summarized in Table 40.

The interpretation of CSI values suggested by those who proposed the index, Conroy et al. (20) and Kramer (21), is that surface waters having a CSI of <3 are generally stable to acid precipitation and those with CSI values 4 to 6 are unstable. The data presented above show that a high proportion of New England and northeastern New York surface and groundwaters were in borderline or unstable condition.

The tendency of the raw waters sampled to dissolve calcium carbonate and to have corrosive effects on water mains and metallic plumbing materials is shown in Table 41. Of the raw waters sampled in Rounds 1 and 2, 97

TABLE 36. ROUND 1 - RAW SURFACE WATER ALUMINUM VALUES COMPARED WITH ALKALINITY AND pH

State	Aluminum (mg/L)	Alkalinity (mg/L as $CaCO_3$)	pH
Connecticut	0.1	1.8	5.46
	0.3	167.3	7.97
Maine	0.1	11	7.00
	0.1	7.5	6.61
	0.2	1.2	4.82
Massachusetts	0.1	3.4	5.28
	0.1	1.25	5.62
	0.1	7.53	6.81
	0.1	4.3	5.83
	0.1	<0.2	4.30
	0.2	1.0	5.24
	0.2	8.6	6.56
	0.1	1.0	5.35
	0.1	5.2	7.64
	0.1	2.9	6.01
	0.1	6.3	6.93
	0.1	6.42	6.92
New Hampshire	0.1	3.4	6.78
	0.1	0.4	5.79
	0.1	11.7	7.05
	0.1	28.4	6.72
	0.1	0.8	5.78
	0.3	0.0	5.37
	0.1	2.2	6.35
Rhode Island	0.2	<0.2	5.49
	0.1	1	5.80
	0.2	20.9	7.13
Vermont	0.3	23.9	6.76
	0.1	8.2	6.77
	0.2	6	6.28
	0.2	20	6.37
New York	0.1	5	5.90
	0.1	<0.2	4.88

Aluminum vs. Alkalinity:
y = 0.127
Slope = 0.0011
r = 0.483

Aluminum vs. pH:
y = 0.089
Slope = 0.008
r = 0.106

TABLE 37. ROUND 1 - RAW GROUNDWATER ALUMINUM VALUES COMPARED WITH ALKALINITY AND pH

State	Aluminum (mg/L)	Alkalinity (mg/L as $CaCO_3$)	pH
New Hampshire	0.3	5.36	5.46
New York	0.3	3	5.15
Vermont	0.1	43.6	5.97

Aluminum vs. Alkalinity:
y = 0.321
Slope = -0.005
r = -0.999

Aluminum vs. pH:
y = 1.66
Slope = -0.26
r = -0.93

Note: Alkalinity Values of <0.2 counted as 0 for above calculations.

TABLE 38. ROUND 2 - RAW SURFACE WATER ALUMINUM VALUES COMPARED WITH ALKALINITY AND pH

State	Aluminum (mg/L)	Alkalinity (mg/L as $CaCO_3$)	pH
Connecticut	0.1	22	7.2
	0.1	3.8	6.0
	0.3	<0.1	4.57
Massachusetts	0.2	1.3	4.16
	0.35	2.4	5.01
	0.1	6.5	7.18
	0.1	0.5	6.20
	0.1	1.2	-
	0.2	2.8	6.38
	0.1	<0.1	5.58
	0.1	<0.1	5.6
New Hampshire	0.1	<0.1	5.75
	0.3	<0.1	5.58
	0.2	<1	5.39
	0.1	1.0	6.43
New York	0.1	1.0	5.70
	0.2	2.4	6.43
	0.2	<0.1	5.35
Rhode Island	0.3	<0.1 (0)	4.65
	0.1	1.5	6.36
	0.2	0	4.88
	0.1	1.3	6.27

Aluminum vs. Alkalinity

y = 0.175
Slope = -0.004
r = -0.229

Aluminum vs. pH

y = 0.544
Slope = -0.065
r = -0.628

Note: Alkalinity values <0.1 counted as 0 for above calculations.

TABLE 39. ROUND 2 - RAW GROUNDWATER ALUMINUM VALUES COMPARED WITH ALKALINITY AND pH

State	Aluminum (mg/L)	Alkalinity (mg/L as $CaCO_3$)	pH
Massachusetts	0.1	18.7	6.80
	0.1	53.5	5.99
	0.1	8.4	-
New Hampshire	0.1	10.0	6.04
	0.2	17	5.64
	0.3	5	5.37
	0.1	20	6.10
	0.1	11	5.77
	0.1	5.5	5.97
	0.1	9.0	5.99
	0.1	11	6.19
	0.4	2	4.93
New York	0.1	58	5.0
Rhode Island	0.1	6.4	5.76
	0.1	17	5.98
	0.1	9	5.84
Vermont	0.2	72.1	8.51

Aluminum vs. Alkalinity

y = 0.150
Slope = -0.0005
r = -0.112

Aluminum vs. pH

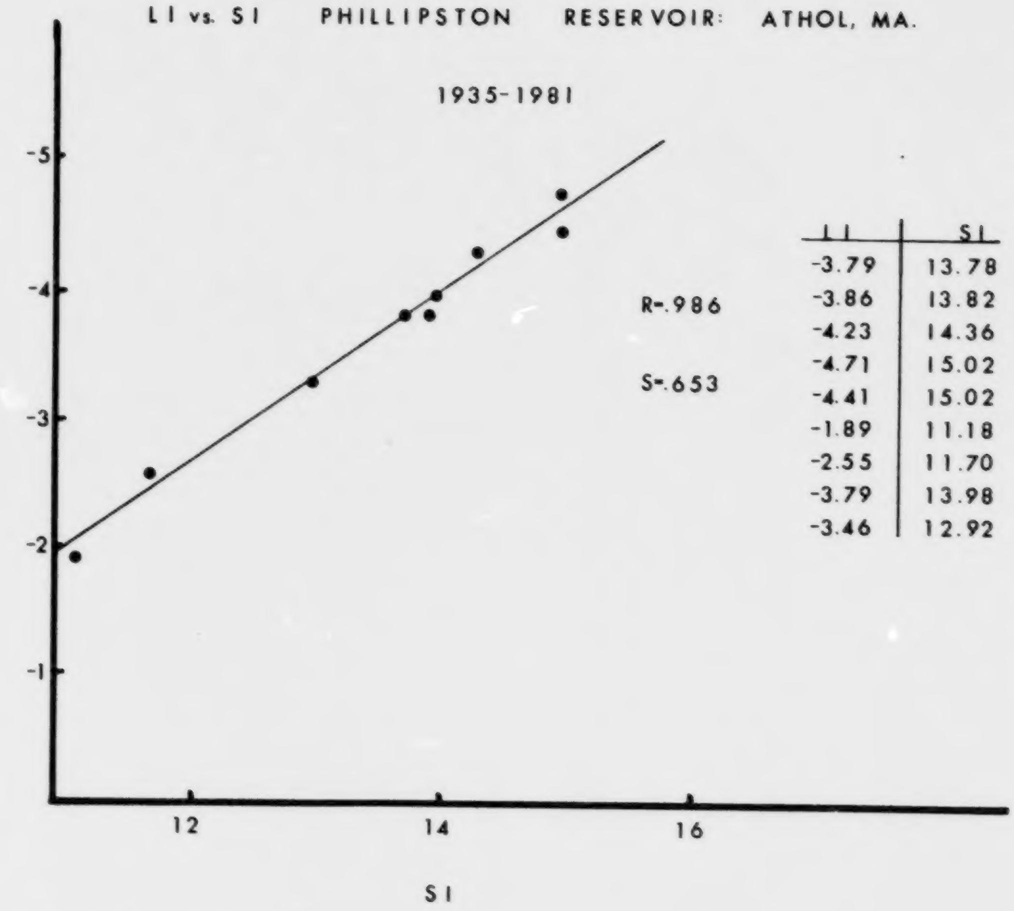
y = 0.283
Slope = -0.023
r = -0.210

TABLE 40. ROUND 3 - RAW GROUNDWATER ALUMINUM VALUES COMPARED WITH ALKALINITY AND pH

State	Aluminum (mg/L)	Alkalinity (mg/L as $CaCO_3$)	pH
	Coastal		
Martha's Vineyard, Massachusetts	0.39	<0.1	4.31
New Jersey	0.1	0.71	4.52
	0.1	3.82	4.45
	0.3	<0.1	4.15
	0.3	<0.1	4.16
	Appalachian		
Pennsylvania	0.1	35.7	6.57
	0.2	10.8	5.57
	0.2	1.94	4.74
	0.1	<0.1	4.67

Coastal		Appalachian	
Al vs. Alkalinity	Al vs. pH	Al vs. Alkalinity	Al vs. pH
y = 0.290	y = 2.85	y = 0.167	y = 0.256
Slope = -0.0569	Slope = -0.606	Slope = -0.0014	Slope = -0.020
r = -0.718	r = -0.771	r = -0.404	r = 0.302

Note: Alkalinity values <0.1 counted as 0 for above calculations.



LI	SI
-3.79	13.78
-3.86	13.82
-4.23	14.36
-4.71	15.02
-4.41	15.02
-1.89	11.18
-2.55	11.70
-3.79	13.98
-3.46	12.92

Figure 15. Langelier Index (LI) vs. Stability Index (SI) at Phillipston Reservoir

TABLE 41. DATA ON THE CORROSIVE NATURE OF RAW WATER SUPPLIES IN THE STUDY AREA

ROUNDS 1 AND 2

Index	Value	Category of Interpretation	% Supplies In Category Rnd.1 (G&S)	Rnd.2 (G&S)	Rnd.2 (G)
CSI	>3	Susceptible or highly susceptible to change	63	79	72
LI	<-2		85	97	91
AI	<10.0	Highly aggressive	85	91	88
SI	>8		97	96	96

percent were in the range on Ryznar's Stability Index where corrosion and red water (rusty water) problems were observed. The low calcium and pH values observed in many of the water supplies could also be detrimental to asbestos-cement pipe, unless checked by natural or synthetic inhibitors.

Table 30 showed results of analyzing household water samples. Table 30 also has data on the Langelier Index values for the waters tested. When lead exceeded 0.05 mg/L or copper exceeded 1 mg/L or when both of these concentrations were exceeded, the highest Langelier Index value was -0.53, the median was -4.44, and the lowest value was -7.65. When neither copper nor lead exceeded the concentrations stated above, the highest L.I value was +0.19, the median was between 4.00 and 4.32 and the lowest value was -9.31. This range of values exceeded the range of the L.I. values for which lead or copper limits were exceeded.

The inability of the Langelier Index to serve as a predictor of corrosion is consistent with the observations of Singley (14). Absence of high levels of corrosion products (lead or copper) in tap water could be a results of the absence of copper piping or lead piping or of lead-tin solder in the system. Another factor that could result in low levels of lead or copper in water is use of corrosion inhibitors not related to calcium carbonate chemistry, e.g. silicates or phosphates. These inhibitors do little to change the Langelier Index.

A different perspective for considering the data in Table 30 is to state that of the 42 water samples with negative LI values, half exceeded copper or lead limits or both in one or more of the household samples. This observation, together with Ryznar's failure to observe corrosion and scaling conditions simultaneously, suggests that negative LI values are not desirable unless certain corrosion inhibitorsor specific control strategies are used.

The raw groundwater data obtained in Round 3 showed the contrast between sand aquifers (New Jersey Pine Barrens area and Martha's Vineyard, Massachusetts) and aquifers in the Appalachian Mountain region from Pennsylvania to North Carolina. Results are summarized in Table 42. Waters from sand aquifers had low alkalinities and pH values, which resulted in corrosion index values showing very strong tendencies to dissolve calcium carbonate. The buffering capacity of the sand aquifers was very small. In contrast, water samples from the Appalachian area were much less likely to have very strong tendencies to dissolve calcium carbonate and buffering capacity was high. These results suggest that sand aquifers have the potential to contain waters that are highly corrosive.

TABLE 42. DATA ON THE CORROSIVE NATURE OF WATER SUPPLIES IN COASTAL AND APPALACHIAN STATES

ROUND 3

Index	Value	Category of Interpretation	% Supplies In Category	
			Coastal	Appalachian
CSI	>3	Susceptible or highly susceptible to change	86	23
LI	<-2		100	42
AI	<10.0	Highly aggressive	100	36
SI	>8		100	68

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APPENDIX I

LOCATION OF WATER SUPPLIES SURVEYED IN THIS STUDY

(Community numbers shown on state maps)

WATER SUPPLIES SURVEYED

CONNECTICUT

ROUND 1 & 2

No.	Town	Supply Name	Source Ground or Surface
1	Bridgeport	Easton Reservoir	S
2	New Haven	Lake Whitney	S
3	Hartford	Nepoug Reservoir	S
4	Wallingford	Pine River Reservoir	S
5	Groton	Poguonnack Reservoir	S
6	Putnam	Little River	S
7	Middletown	River Rd. Wells	G
8	Greenwich	Putnam Lake Reservoir	S
9	Portland	*Portland Reservoir	S
10	Norwich	*Deep River Reservoir	S
11	Meriden	Broad Brook Reservoir	S
	Meriden	Elmere Reservoir	S
12	Torrington	Reuben Hart Reservoir	S
13	Danbury	West Lake	S
	Danbury	Margerie Reservoir	S
14	Danielson	Hygrea Reservoir	S
15	Willimantic	Natchaug Reservoir	S
16	Clinton	Killingworth Reservoir	S
17	CT. Water Co.	Stafford Springs	G
18	Waterbury	Wigwam Reservoir	S

*Supplies that were retested

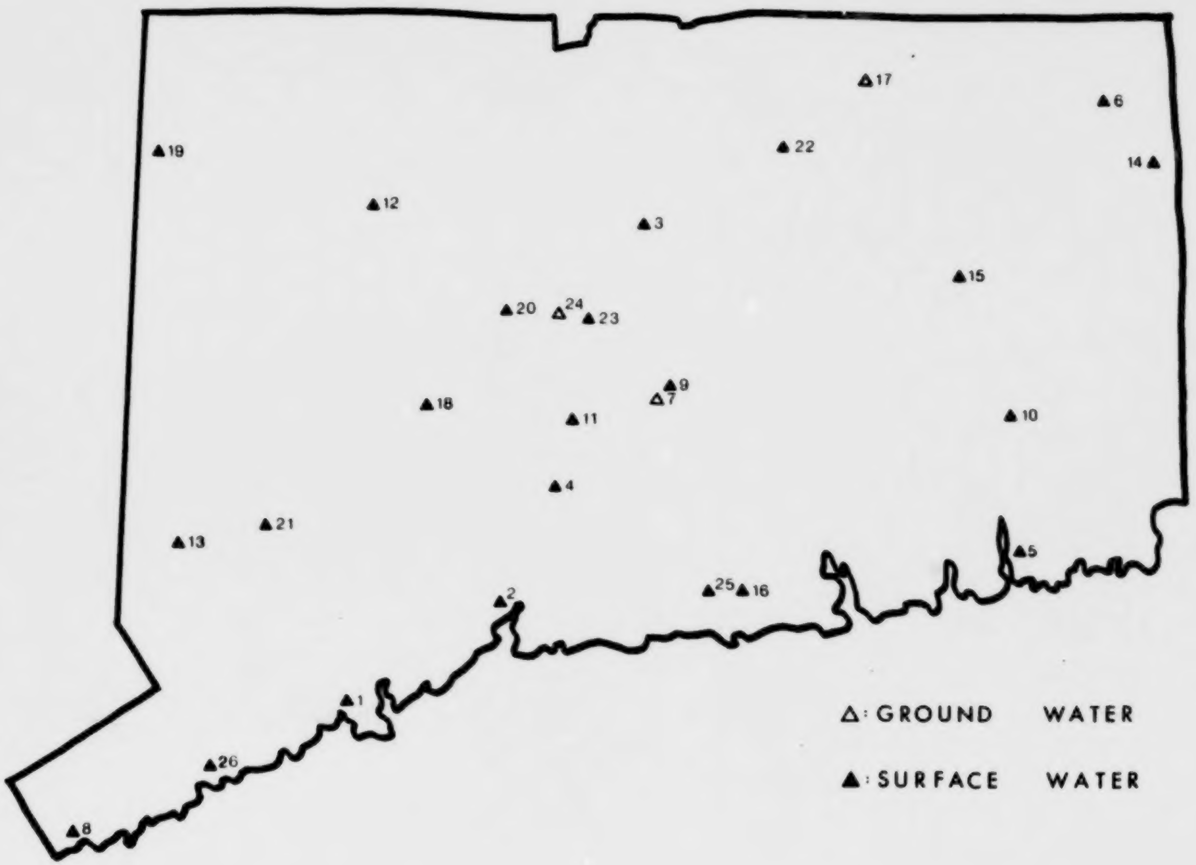
WATER SUPPLIES SURVEYED

CONNECTICUT - ROUND 1 & 2 - (CONTINUED)

19	Sharon Sharon	Beardsley Reservoir Caulkinston Reservoir	S S
20	Bristol	*Reservoir No. 1	S
21	Newton	Taunton Pond	S
22	Rockville	Shenipsit Lake	S
23	New Britian	Shiffle Mead Reservoir	S
24	Plainville	Woodford Wells	G
25	Ct. Water Co.	Kelseytown Reservoir	S
26	Norwalk	Plant Effluent - Norwalk 1st Taxing District	S

*Supplies that were retested

CONNECTICUT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WATER SUPPLIES SURVEYED

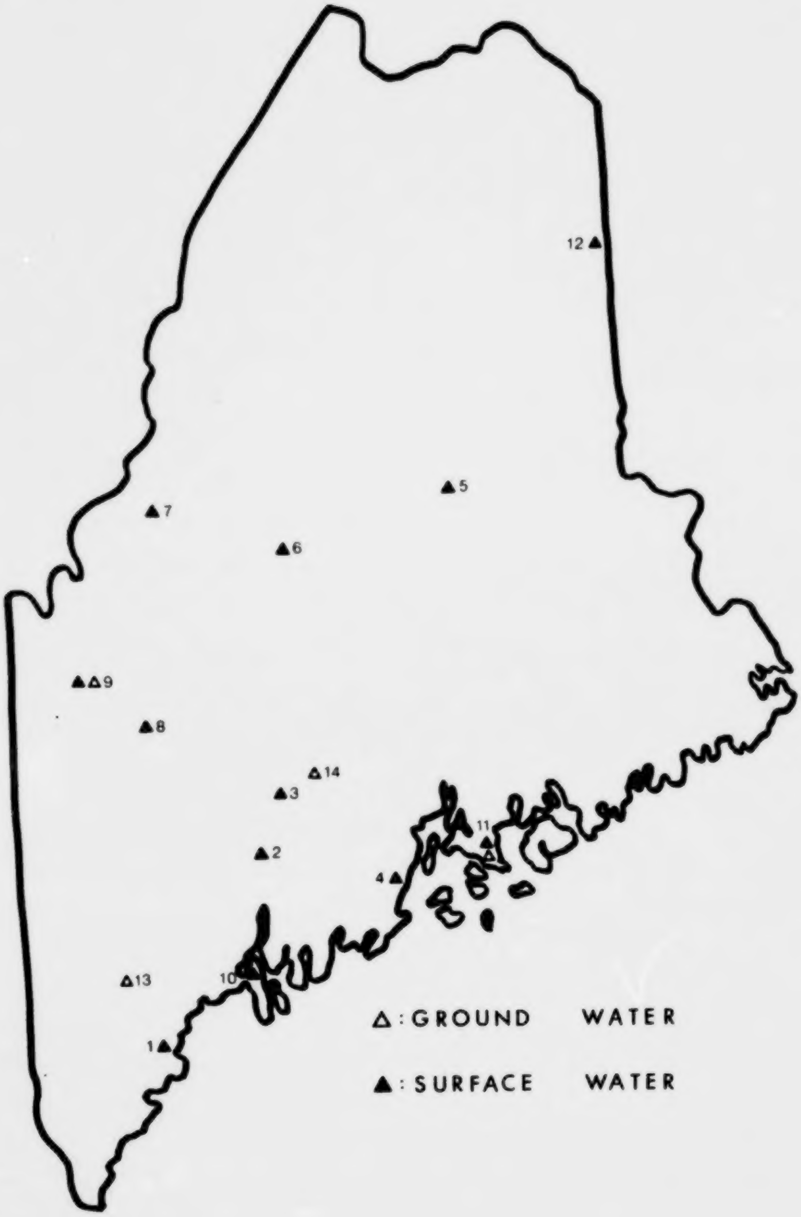
MAINE

ROUND 1 & 2

No.	Town	Supply Name	Source Ground or Surface
1	Portland	Sebage Lake	S
2	Augusta	Carlton Pond	S
3	Waterville	China Lake	S
4	Camden-Rockland	Mirror Lake	S
5	Millinocket	Ferguson Pond	S
6	Greenville	Big Squaw Pond	S
7	Jackman	Bigwood Pond	S
8	Phillips	Mount Blue Pond	S
9	Rangley	*Rangley Lake	S
	Rangley	Mingo Spring	G
10	Bath	*Nequasset Lake	S
11	Stonington	*Burntland Pond	S
	Stonington	2 Private Wells	G
12	Mars Hill	Young Lake	S
13	North Windham	*N. Windham Municipal Supply	G
14	Clinton	Clinton Municipal Supply	G

*Supplies that were retested

MAINE



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WATER SUPPLIES SURVEYED

MASSACHUSETTS

ROUND 1 & 2

No.	Town	Supply Name	Source Ground or Surface
1	Athol	*Phillipston Reservoir	S
	Athol	Newton Reservoir	S
	Athol	South Street Well	G
2	Boston	*Intake Wachusett Tunnel	S
	Boston	*Upper Wachusett Reservoir	S
3	Boston	*Quabbin Reservoir-Lower End	S
	Boston	*Quabbin Reservoir-Outlet	S
4	Cambridge	Upper Hobbs Brook Reservoir	S
5	Dalton	Egypt Brook Reservoir	S
6	Fall River	*North Watuppa Pond	S
7	Falmouth	Long Pond Reservoir	S
8	Fitchburg	*Lovell Reservoir	S
9	Gardner	Crystal Lake	S
10	Gloucester	Dikes Meadow Reservoir	S
11	Hinsdale	*Belmont Reservoir	S
12	Holyoke	Carmody Reservoir	S
13	Lakeville	Elders Pond	S
14	Leominster	*Fall Brook Reservoir	S
	Leominster	No. Town Reservoir at Dam	S
	Leominster	Well No. 120	G
15	Lee	*Leahey Reservoir	S
16	Montague	Lake Pleasant	S
17	Northampton	Mountain St. Reservoir	S

*Supplies that were retested

WATER SUPPLIES SURVEYED

MASSACHUSETTS - ROUND 1 & 2 - (CONTINUED)

18	Plymouth	Little South Pond	S
	Plymouth	Lout Pond	S
	Plymouth	Federal Furnace Well	G
	Plymouth	North Plymouth Well	G
19	Pittsfield	*Farnham Reservoir	S
20	Salem-Beverly	Wenham Lake	S
21	Southbridge	Hatchett Brook Reservoir No. 3	S
22	Spencer	Shaw Pond Reservoir	S
23	Springfield	Cobble Mountain Reservoir	S
24	Westfield	Upper Granville Reservoir	S
25	Winchendon	*Upper Naukeag Lake	S
26	Worcester	Pine Hill Reservoir Upper End	S
	Worcester	Pine Hill Reservoir at Dam	S
27	New Bedford	Litte Quittacas Reservoir	S
28	Groton	Groton Reservoir	S
29	Lanesboro	Well No. 1	G
	Lanesboro	Well No. 2	G
30	Bourne	Well No. 3 (USGS No. BHW-199)	G
31	Brewster	Well No. 1 (USGS No. BMW-37)	G
32	Hudson	Cranberry Bog Well	G
	Hudson	Rimkus Street Well	G
33	Duxbury	Milbrook Well No. 2	G
34	South Wellfleet	B-Well (USGS No. WNW-41)	G
35	Sterling	Well No. 2	G
	Sterling	Well No. 3	G
36	West Boylston	Lee Street Well No. 4	G
	West Boylston	Oakdale Well	G

*Supplies that were retested

WATER SUPPLIES SURVEYED

MASSACHUSETTS - ROUND 1 & 2 - (CONTINUED)

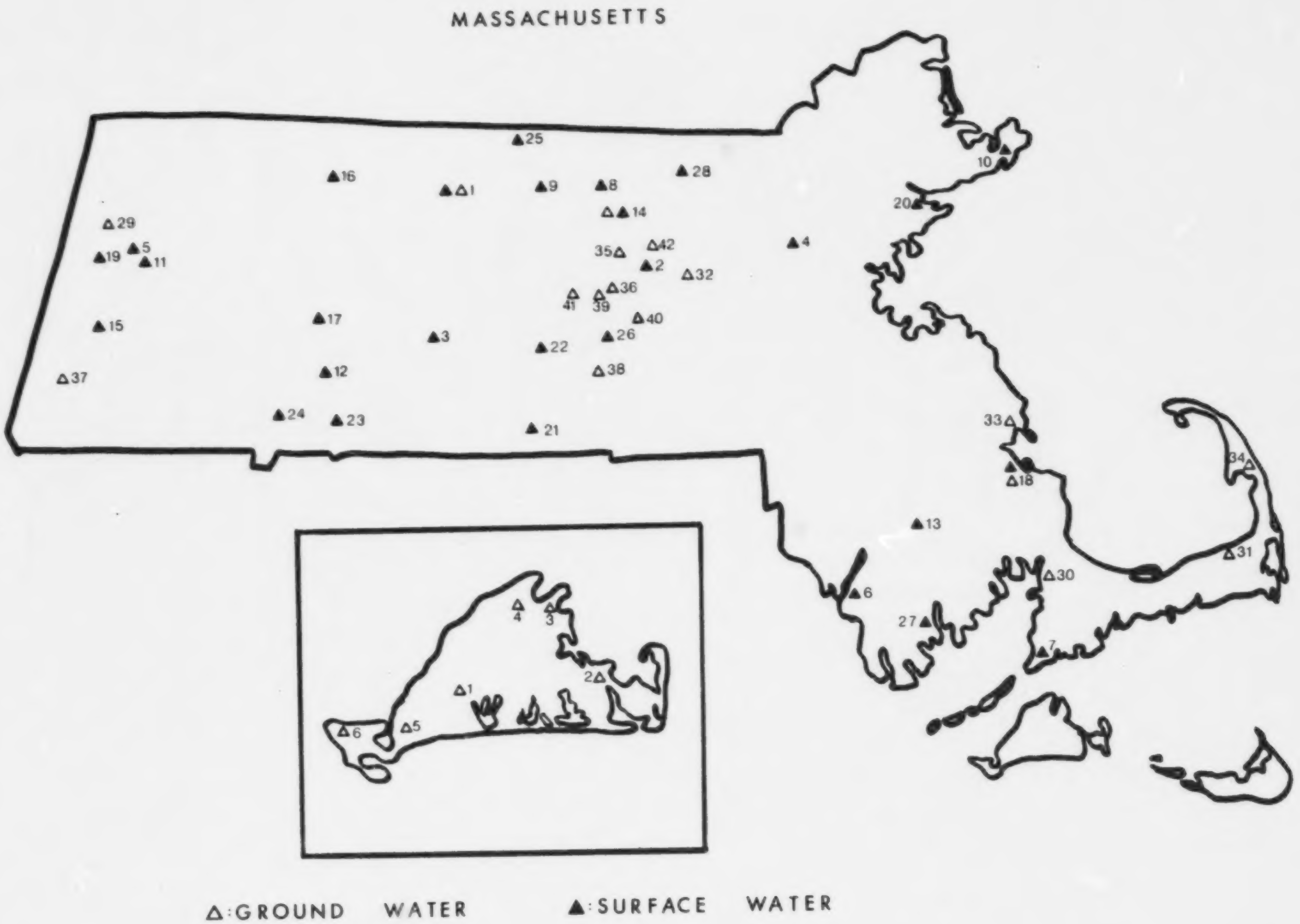
37	Great Barrington	Tap at Monument Mt. Reg. High School	G
38	Auburn	Well No. 1	G
	Auburn	Well No. 5	G
39	Boylston	Well No. 1	G
	Boylston	Well No. 2	G
40	Shrewsbury	Well No. 6	G
	Shrewsbury	Well No. 4	G
41	Holden	Spring Street Well	G
	Holden	Mason Street Well	G
42	Lancaster	Well No. 2	G

WATER SUPPLIES SURVEYED

MARTHA'S VINEYARD

ROUND 3

No.	Town	Supply Name	Source Ground or Surface
1	West Tisbury	Greenlands	G
2	Edgartown	Edgartown Water Co.	G
3	Oak Bluffs	Oak Bluffs Water Dept.	G
4	Vineyard Haven	Tisbury Water Dept.	G
5	Chilmark	Town Hall Well	G
6	Gay Head	Gay Head Town Hall	G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WATER SUPPLIES SURVEYED

NEW HAMPSHIRE

ROUND 1 & 2

No.	Town	Supply Name	Source Ground or Surface
1	Andover	Bradley Lake	S
2	Ashland	Impoundment Reservoir	S
3	Boscawen	Walker Pond	S
4	Canaan	Canaan St. Lake	S
5	Claremont	Dole Reservoir	S
6	Concord	Penacook Lake	S
7	North Conway	Kearsarge Reservoir	S
8	Durham	Oyster River Imp.	S
9	Georges Mills	*Ledge Pond	S
	Georges Mills	2 Private Shallow Wells	G
10	Gorham	Perkins Brook Imp. Reservoir	S
11	Hampton	Crenshaw Well No. 10	G
12	Hillsboro	Loon Pond	S
13	Hooksett	*Well No. 2	G
	Hooksett	2 Private Shallow Wells	G
14	Hudson	*Small Tarnic Well	G
	Hudson	Weinstein Well (Litchfield)	G
	Hudson	W & E Well (Windham)	G
	Hudson	High Plains P.S. (Litchfield)	G
15	Jaffrey	Bullet Pond	S

*Supplies that were retested

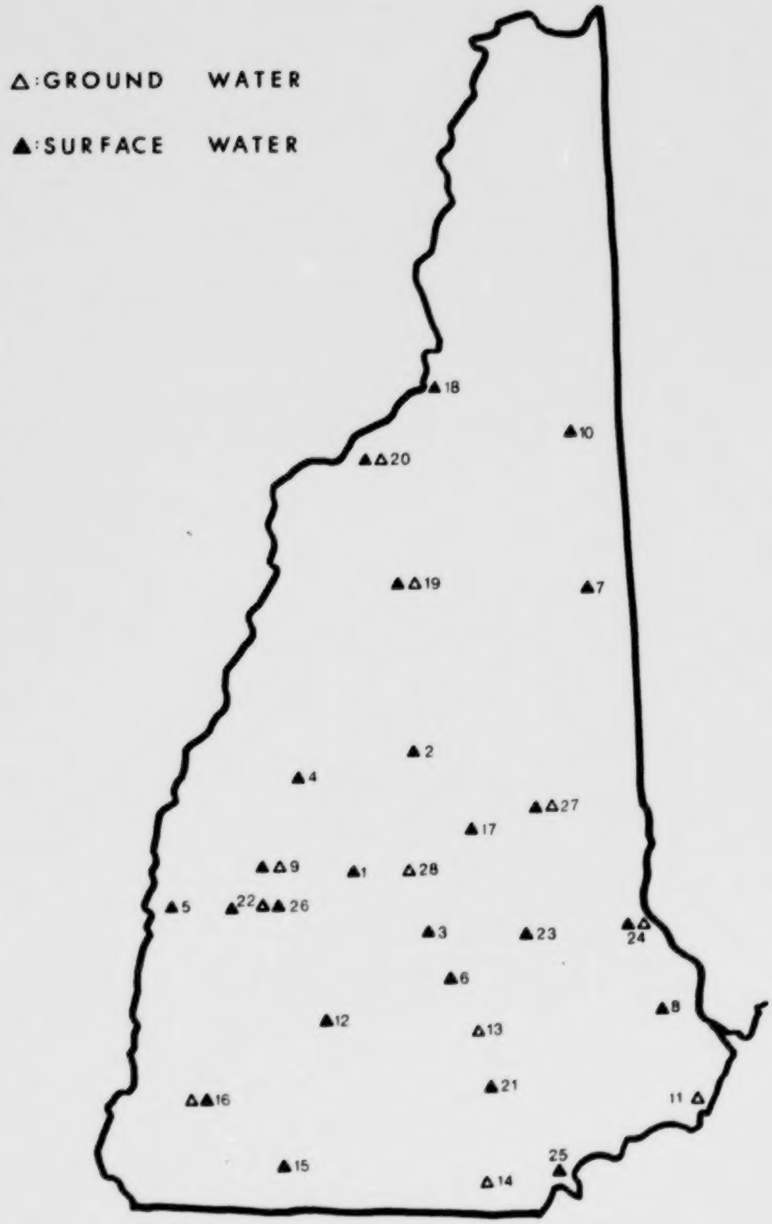
WATER SUPPLIES SURVEYED

NEW HAMPSHIRE - ROUND 1 & 2 - (CONTINUED)

16	Keene	*Babbidge Reservoir	S
	Keene	West St. Well No. 1	G
	Keene	Court St. Well No. 4	G
	Keene	Private Shallow Well	G
17	Laconia	Paugus Bay	S
18	Lancaster	Garland Brook	S
19	Lincoln	*Imp. Reservoir at Loon Mt.	S
	Lincoln	Bradley Field Well (Woodstock)	G
	Lincoln	Private Dug Well	G
20	Littleton	*Gale River Dam	S
	Littleton	3 Private Dug Wells	G
21	Manchester	Massahesic Lake	S
22	Newport	Gilman Pond	S
23	Pittsfield	Berry Pond	S
24	Rochester	*Round Pond	S
	Rochester	3 Private Shallow Wells	G
25	Salem	Canobie Lake	S
26	Sunapee	*Lake Sunapee	S
	Sunapee	3 Private Shallow Wells	G
27	Wolfeboro	*Upper Beech Pond	S
	Wolfeboro	2 Private Shallow Wells	G
28	Franklin	*ACME Well	G
	Franklin	Sanbornton Well Field	G
	Franklin	Private Shallow Well	G

*Supplies that were retested

NEW HAMPSHIRE



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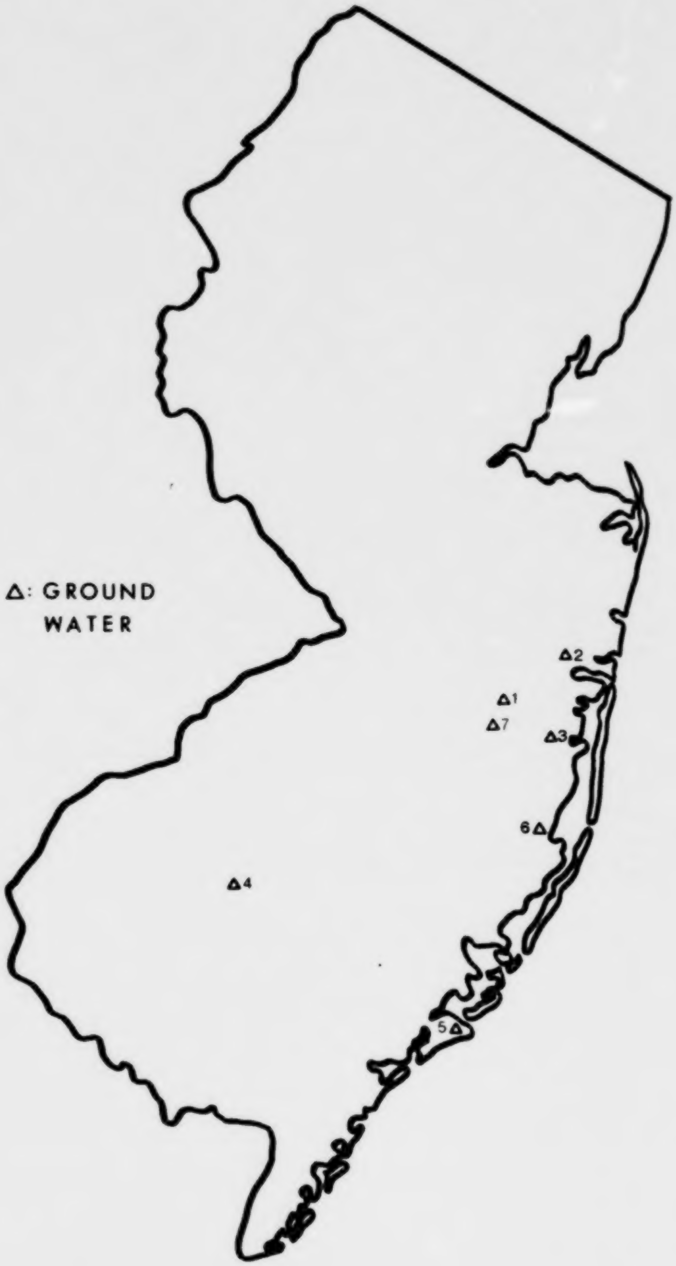
WATER SUPPLIES SURVEYED

NEW JERSEY

ROUND 3

No.	Town	Supply Name	Source Ground or Surface
1	Lakehurst	Well No. 1	G
2	Brick Township	Well No. 5	G
3	Beachwood	Well No. 4	G
4	Winslow	Well No. 3	G
5	Atlantic City	Well No. 4	G
6	Barnegat	Well No. 4	G
7	Manchester	Crestwood Vill.Water Co. Well No. 7	G

NEW JERSEY


Δ: GROUND WATER
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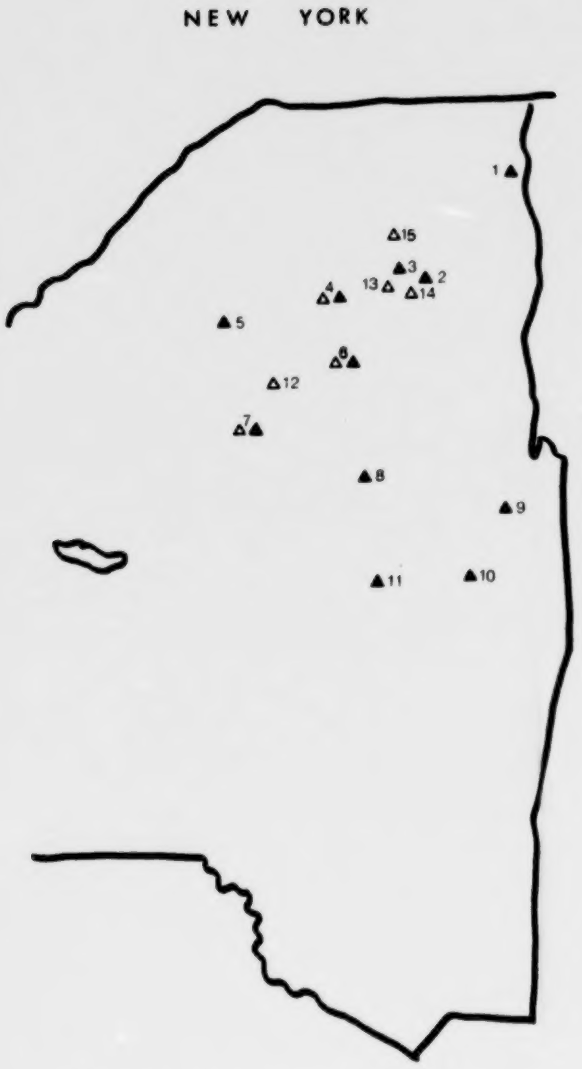
WATER SUPPLIES SURVEYED

NEW YORK

ROUND 1 & 2

No.	Town	Supply Name	Source Ground or Surface
1	Plattsburg	Municipal Water Dept.	S
	Plattsburg	Meade Reservoir	S
	Plattsburg	West Brook	S
	Plattsburg	Patkinson Reservoir	S
2	Lake Placid	*Lake Placid	S
3	Saranac Village	*Mackenzie Pond	S
4	Tupper Lake Vill.	*Simon Lake	S
	Tupper Lake Vill.	Lumberjack Spring	G
	Tupper Lake Vill.	Dug Well at Mt. Morris Motel	G
5	Star Lake	Star Lake	S
6	Long Lake	*Big Sand Reservoir	S
	Long Lake	Drilled Well-Adirondack Mt.Sch.	G
	Long Lake	Spring-Private Dwelling	G
7	Old Forge	*Independence Lake	S
	Old Forge	Ground Water Supply No. 1	G
8	Speculator	Lake Pleasant	S
9	Glens Falls	Glens Falls Municipal Supply	S
10	Saratoga Springs	Saragtoga Springs Mun.Supply	S
11	Gloversville	Gloversville Mun. Supply	S
12	Covewood Lodge	*Private Supply (spring)	G
13	Adirondack Ed.Ctr.	Deep Well-Supply for State Fac.	G
14	Ray Brook	R.B.Mun.Supply.-Shallow Well	G
15	Tamarac Inn	Private Supply-Drilled Well	G

*Supplies that were retested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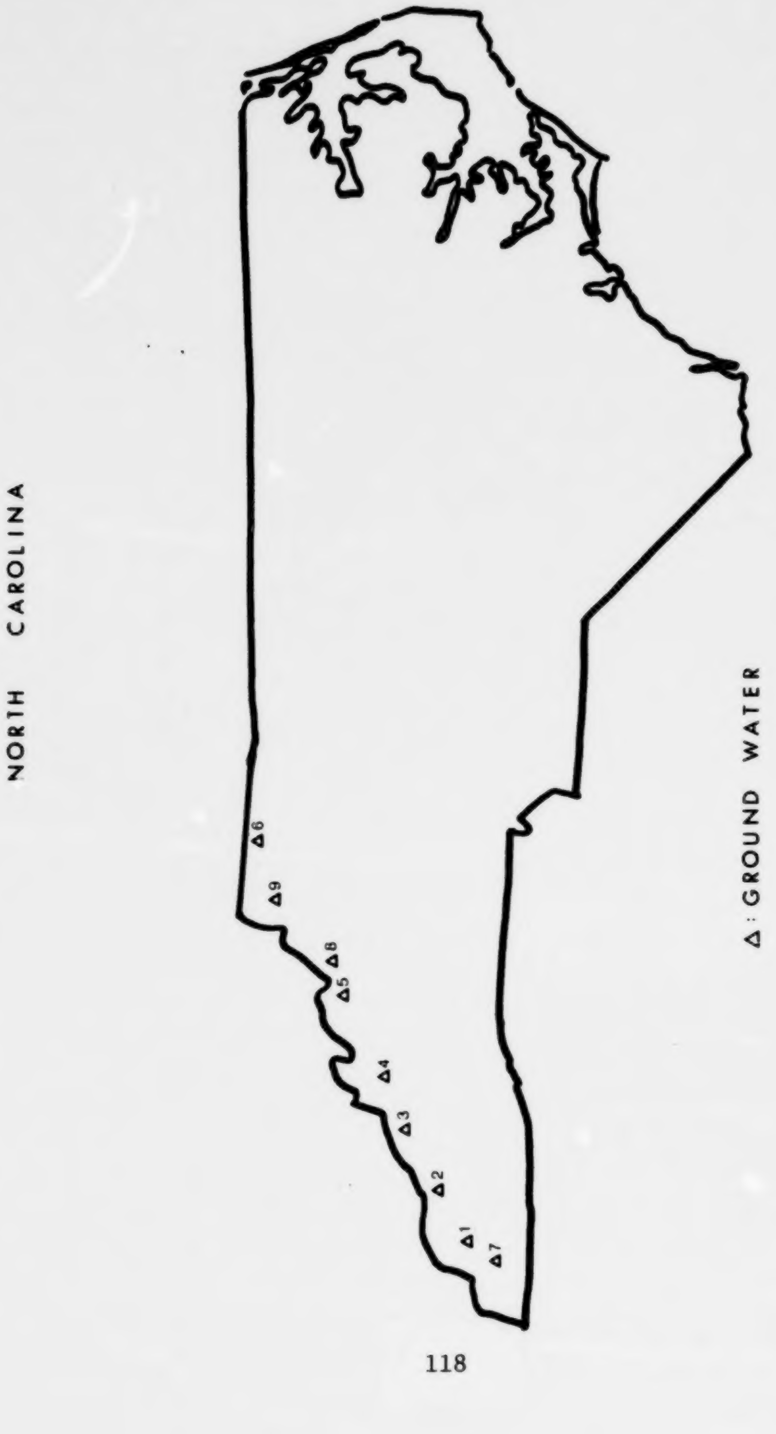
△: GROUND WATER
▲: SURFACE WATER

WATER SUPPLIES SURVEYED

NORTH CAROLINA

ROUND 3

No.	Town	Supply Name	Source Ground or Surface
1	Robbinsville	Thunderbird Mt. Resort	G
2	Cherokee	Soco Valley Well	G
3	Waterville	I-40 Rest Stop(10 mi.from Tenn.)	G
4	Marshall	Well No. 6	G
5	Bakersville	Well No. 1	G
6	Sparta	Well No. 9	G
7	Marble	1968 Well	G
8	Newland	Well No. 2	G
9	West Jefferson	Well-West Jefferson Lumberyard	G


NORTH CAROLINA
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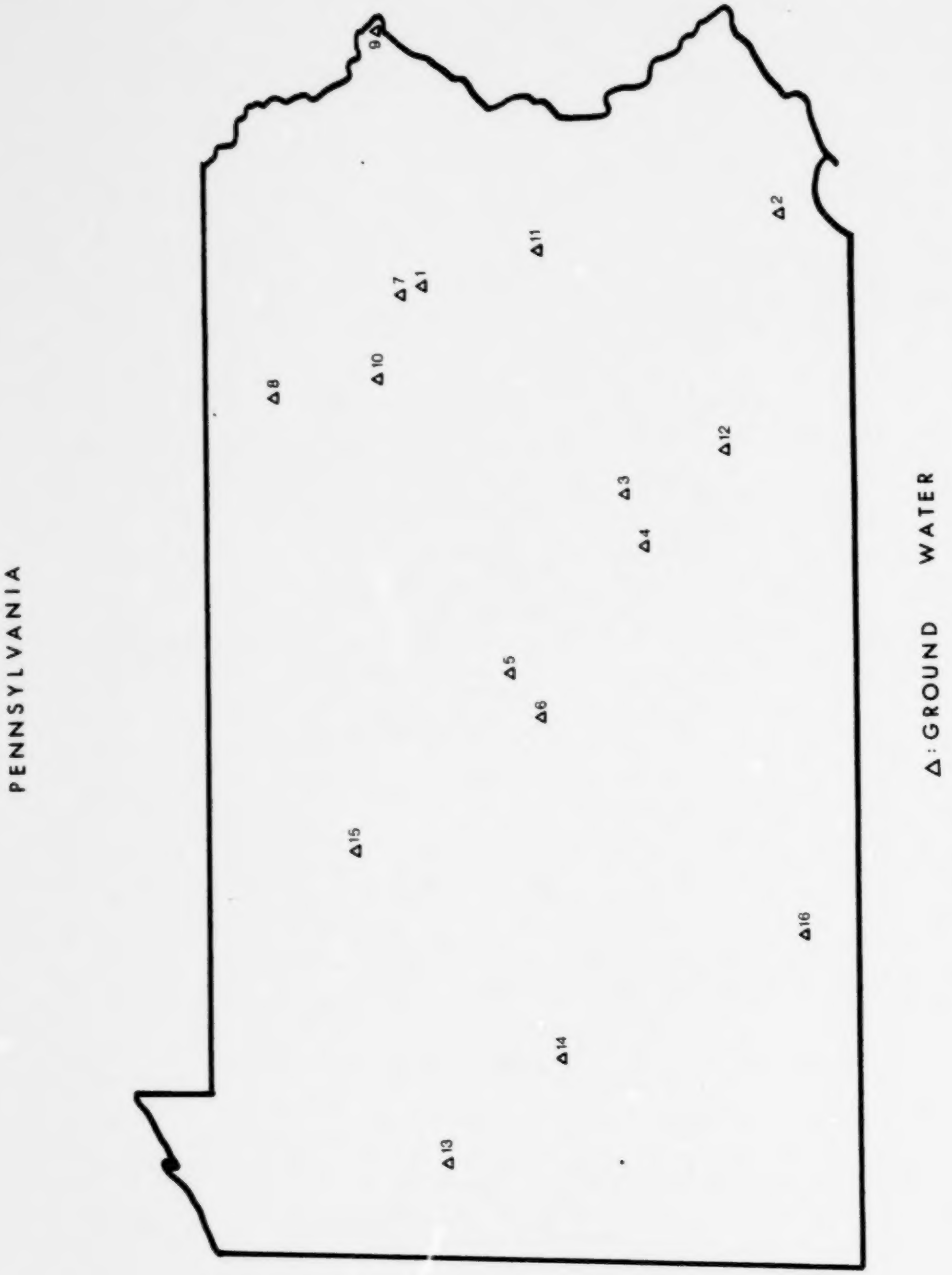
WATER SUPPLIES SURVEYED IN STUDY OF EFFECTS OF ACID RAIN

PENNSYLVANIA

ROUND 3

No.	Town	Supply Name	Source Ground or Surface
1	Plymouth	Well No. 1	G
2	Tredyffrin	Tredyffrin Well	G
3	Millersburg	Well No. 5	G
4	Newport Rd 2	Well No. 3	G
5	Bellefonte	Big Spring	G
6	Black Mashaunan	Main Well	G
7	Dallas	Country Club Well No. 10	G
8	Towanda	Well No. 1	G
9	Matamoras	Well No. 3	G
10	Promised Land State Park		G
11	Jim Thorpe	Well No. 1	G
12	Middletown	Well No. 1	G
13	Grove City	Well No. 3	G
14	Ford City	Well No. 3	G
15	Johnsonburg	Well No. 2	G
16	Berlin	Boost Spring	G
	Berlin	Well No. 7	G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WATER SUPPLIES SURVEYED

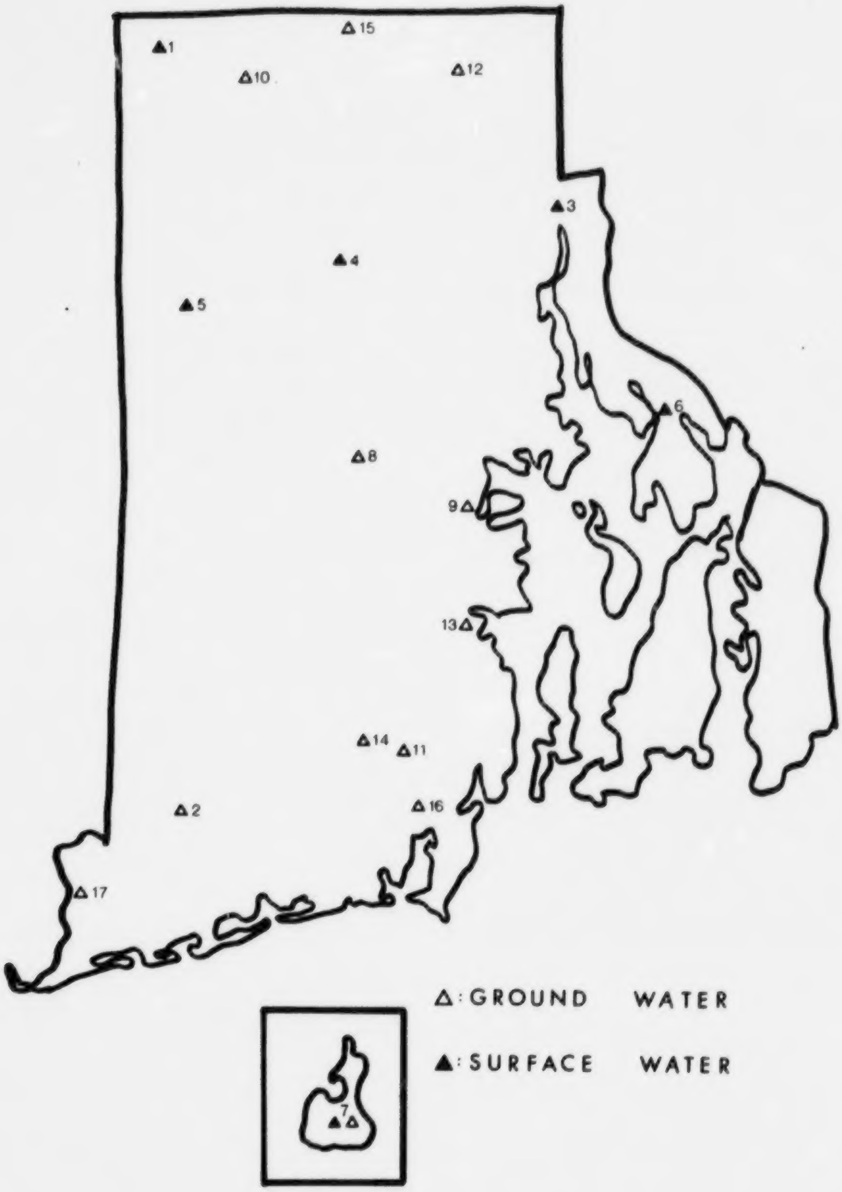
RHODE ISLAND

ROUND 1 & 2

No.	Town	Supply Name	Source Ground or Surface
1	Burriville	*Wallum Lake	S
2	Richmond	*Alton Dug Well	G
3	Pawtucket	Pawtucket Reservoir	S
4	Scituate	*Scituate Reservoir	S
5	Scituate	*Ponaganset Reservoir	S
6	Warren	Kickemuit Reservoir	S
7	Block Island	*Sand Pond	S
	Block Island	Finished Sample from Supply Todd's Reservoir	G
8	Coventry	Mishnock Well No. 1	G
9	E. Greenwich	E. Greenwich Well No. 1	G
10	Harrisville	Harrisville Well No. 2	G
11	Kingston	Univ. of R.I. Well No. 4	G
12	Manville	Manville Well No. 10	G
13	N. Kingston	Well No. 4	G
14	West Kingston	Private Dug Well	G
15	Slatersville	Slatersville Dug Well	G
16	Wakefield	Well No. 6	G
17	Westerly	White Rock Wells	G

*Supplies that were retested

RHODE ISLAND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WATER SUPPLIES SURVEYED

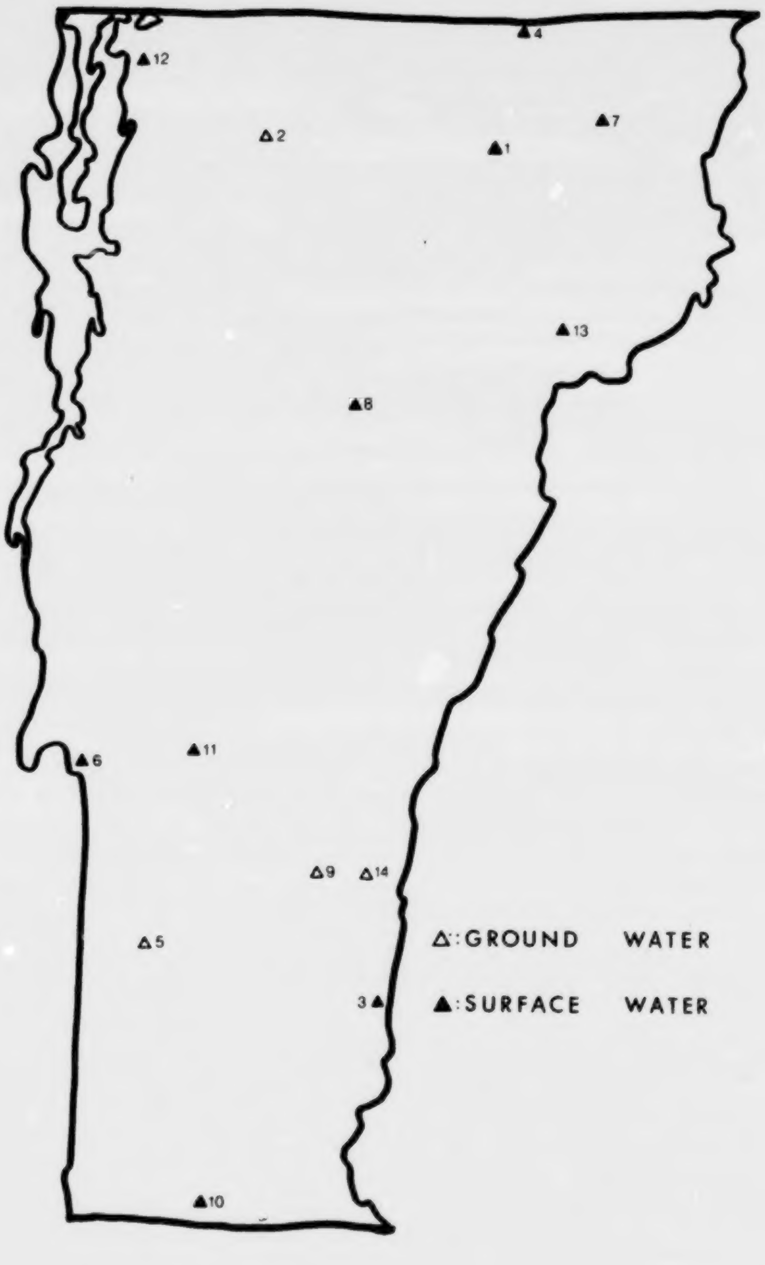
VERMONT

ROUND 1 & 2

No.	Town	Supply Name	Source Ground or Surface
1	Barton	May Pond	S
2	Bakersfield	*Bakersfield Vill.Sply.(Springs)	G
	Bakersfield	Hale Drilled Well	G
	Bakersfield	Lawyer Drilled Well	G
	Bakersfield	Teacher's Drilled Well	G
3	Bellows Falls	Mimard Pond	S
4	Derby Line	Holland Pond	S
5	Dorset	Spring	G
6	Fairhaven	Inman Pond	S
7	Island Pond	2 Brooks on Bluff Mountain	S
8	Montpelier	Berlin Pond	S
9	Proctorsville	New Village Well	G
10	Readsboro	Home's Pond	S
11	Rutland	Mendon Brook	S
12	Swanton	Fairfield Pond	S
13	St. Johnsbury	Stiles Pond	S
14	Cavendish	Cavendish Village Well	G
	Cavendish	Van Shaik Well	G

*Supplies that were retested

VERMONT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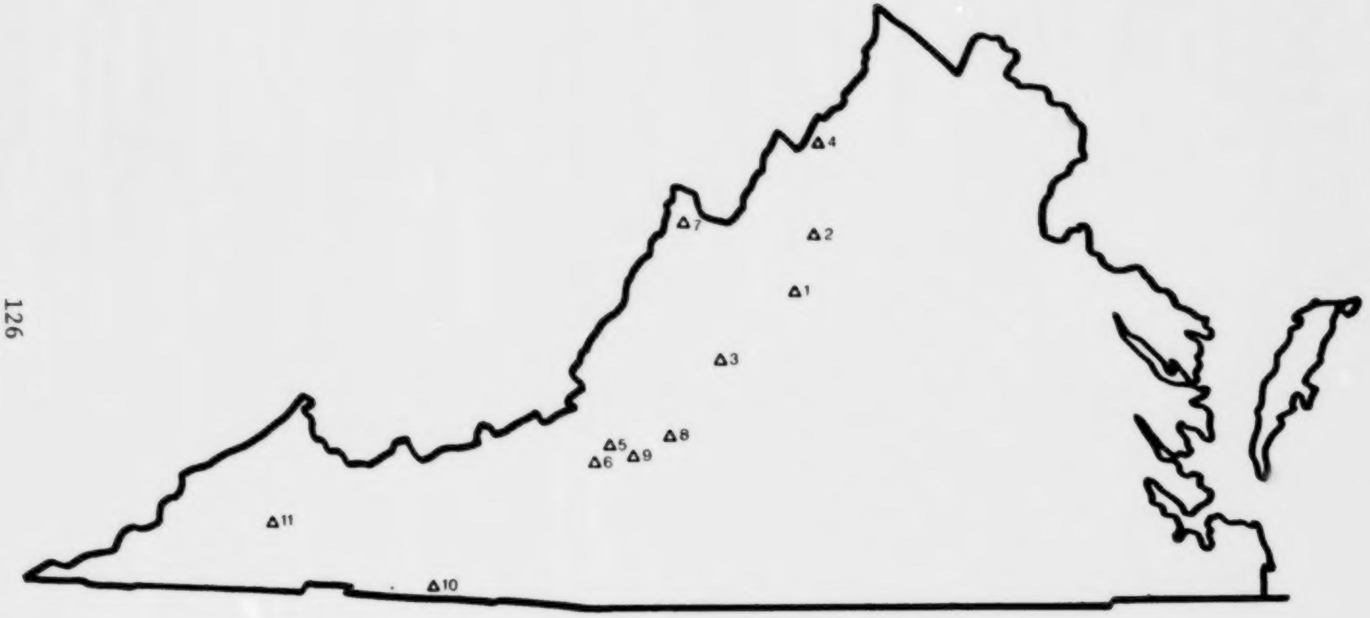
WATER SUPPLIES SURVEYED

VIRGINIA

ROUND 3

No.	Town	Supply Name	Source Ground or Surface
1	Waynesboro	Waynesboro Municipal Well	G
2	McGayesville	McGayesville Water Co.	G
3	Buena Vista	Buena Vista Municipal Supply	G
4	Bayse	Bryce Mt. Well No. 3	G
5	Roanoke County	Moose Lodge 384	G
6	Roanoke County	Mitchell Distributing Co.	G
7	Monterey	Monterey Municipal Supply	G
8	Montvale	Colonial Pipeline Co.	G
9	Vinton	Vinton Municipal Supply	G
10	Independence	Parsons Well	G
11	Cleveland	Cleveland Municipal Supply	G

VIRGINIA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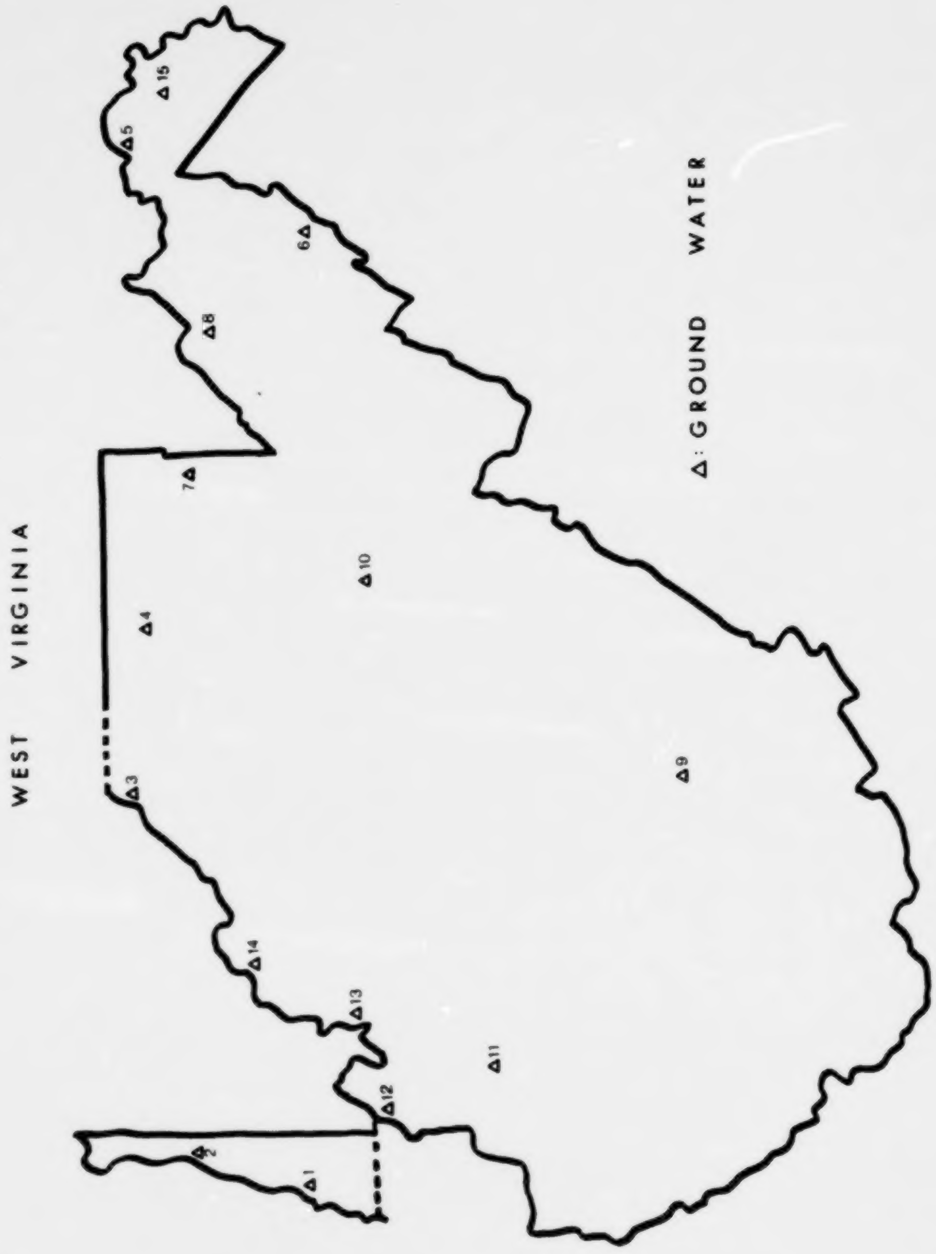
WATER SUPPLIES SURVEYED

WEST VIRGINIA

ROUND 3

No.	Town	Supply Name	Source Ground or Surface
1	Moundsville	Well No. 13	G
2	Wellsburg	Wellsburg Water Works	G
3	New Martinsville	Leap Street Well	G
4	Fairview	Fairview Water Dept.	G
5	Berkeley Springs (Bath)	Berkeley Springs Water Dept.	G
6	Wardensville	Wardensville Water Dept.	G
7	Terra Alta	Terra Alta Water Works	G
8	Mineral County	Wells-Allegheny Ballistics Lab	G
9	Rainelle	Well No. 5	G
10	Norton	Norton Water Dept.	G
11	Eleanor	Well No. 4-Coralynn Co.,Inc.	G
12	Point Pleasant	Ranney Well	G
13	Ravenswood	Well No. 3	G
14	Parkersburg	Parkersburg Water Dept.	G
15	Bunker Hill	Berkeley County Public Service Distributor (Spring)	G


WEST VIRGINIA
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APPENDIX II

QUALITY ASSURANCE/QUALITY CONTROL DATA

TABLE II-1. SUMMARY OF SAMPLE PRESERVATION METHODS UTILIZED IN THIS STUDY

SAMPLE PRESERVATION METHODS

	Acidification with 1.5 mL/L Concentrated HNO_3 Upon Collection	Refrigeration After Receipt	Acidification with 2 mL/L Concentrated Sulfuric Acid Upon Receipt	No Preservation	PVC or High-Density Linear Polyethylene Bottles Having Screw Caps with Conical Polyethylene Liners
Color				x	
Total Dissolved Solids				x	
Chloride	x	xa		x	
Sulfate				x	
Nitrate-N			x		
Barium	x				
Arsenic	x				
Selenium	x				
Fluoride			x		
Titration Alkalinity					x
Specific Conductance				x	
Copper	x				
Manganese	x				
Lead	x				
Iron	x				
Cadmium	x				
Zinc	x				
Mercury	x				
Sodium	x				
Potassium	x				
Calcium	x				
Magnesium	x				
PO_4-P		x			
Total-P		x			
Reactive SiO_2		x			

Note: a. Samples that were analyzed by the automated colorimetric method.

TABLE II-2. SUMMARY OF TYPES OF ANALYTICAL METHODS USED FOR THE DIFFERENT CONSTITUENTS INVESTIGATED IN THIS STUDY

Constituent	Flame Atomic Absorption	Furnace Atomic Absorption	Flame Emission	Cold-Vapor Atomic Absorption	Potentiometric Titration	Direct Potentiometry	Automated Colorimetric	Direct Conductometric	Gravimetric	Other
Color										x
Total Dissolved Solids									x	
Chloride					x		x			
Sulfate							x			
Nitrate -N							x			
Barium	x									
Arsenic		x								
Selenium		x								
Fluoride							x			
Titration Alkalinity					x					
Specific Conductance								x		
pH (field)						x				
Copper	x									
Manganese	x									
Lead		x								
Iron	x									
Cadmium		x								
Zinc	x									
Mercury				x						
Sodium			x							
Potassium			x							
Calcium	x									
Magnesium	x									
PO_4 -P							x			
Total -P							x			
Reactive SiO_2							x			

TABLE II-3. SUMMARY OF ORIGINAL ANALYTICAL PROCEDURE REFERENCES FOR METHODS USED IN THIS STUDY

Constituent	Standard Methods[a]	USEPA[b]	USGS[c]	Other
Color	204A			
Total Dissolved Solids	A.			
Chloride		325.2		B
Sulfate		375.4		
Nitrate -N		353.2[d]		
Barium				
Arsenic		206.2		
Selenium		270.2		
Fluoride	413E			
Titration Alkalinity				C
Specific Conductance		120.1		
pH (field)				D
Copper		220.1		
Manganese		243.1		
Lead		239.2		
Iron		236.1		
Cadmium		213.2[e]		
Zinc		289.1		
Mercury		245.1[f]		
Sodium	320A			
Potassium	317A			
Calcium			I-1152-78	
Magnesium		242.1[g]		
Aluminum		202.2		
Phosphorus - PO_4		365.1	I-2601-78	
Phosphorous - Total		365.1		
Silica (reactive)	425E		I-2700-78	

TABLE II-4. QUALITY CONTROL RESULTS FOR REFERENCE STANDARDS IN POTENTIOMETRIC ALKALINITY TITRATIONS TO THE CARBONIC ACID EQUIVALENCE POINT

STANDARDS WERE NOT CERTIFIED BY THE SAME METHOD
CONCENTRATIONS ARE mg/L as $CaCO_3$

	USGS 62	USGS 70	EMSL 478-1	EMSL 478-3	EMSL 478-4
Reference Value	70.1	22.3	NA	16.1	73.6
Standard Deviation	5.7	1.9	NA	1.5	1.9
True Value	NA	NA	21.7	16.0	73.7
Number of Analyses	8	6	2	23	19
Mean Analysis Value	71.28	20.9	21.3	16.0	73.4
Standard Deviation	0.089	0.43	0.28	0.34	0.22
Coefficient of Variation	0.12	2.1	1.3	2.1	0.30
Percent Bias	-	-	-1.9	0	-0.4

TABLE II-5. FREQUENCY DISTRIBUTION OF STANDARD DEVIATIONS OF ANALYZED ALKALINITIES

Standard Deviation (mg/L $CaCO_3$)	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
0.0002	1	1	1.190	1.190
0.0027	1	2	1.190	2.381
0.0066	1	3	1.190	3.571
0.01	2	5	2.381	5.952
0.012	1	6	1.190	7.143
0.013	1	7	1.190	8.333
0.014	1	8	1.190	9.524
0.02	2	10	2.381	11.905
0.022	1	11	1.190	13.095
0.024	1	12	1.190	14.286
0.026	1	13	1.190	15.476
0.028	1	14	1.190	16.667
0.03	1	15	1.190	17.857
0.031	1	16	1.190	19.048
0.033	1	17	1.190	20.238
0.04	2	19	2.381	22.619
0.041	1	20	1.190	23.810
0.042	1	21	1.190	25.000
0.043	1	22	1.190	26.190
0.045	1	23	1.190	27.381
0.049	2	25	2.381	29.762
0.05	1	26	1.190	30.952
0.052	1	27	1.190	32.143
0.054	1	28	1.190	33.333
0.057	1	29	1.190	34.524
0.06	1	30	1.190	35.714
0.064	1	31	1.190	36.905
0.065	1	32	1.190	38.095
0.066	1	33	1.190	39.286
0.068	1	34	1.190	40.476
0.07	1	35	1.190	41.667
0.073	2	37	2.381	44.048
0.074	1	38	1.190	45.238
0.076	1	39	1.190	46.429
0.08	1	40	1.190	47.619
0.081	1	41	1.190	48.810
0.082	1	42	1.190	50.000
0.085	1	43	1.190	51.190
0.087	1	44	1.190	52.381
0.09	1	45	1.190	53.571
0.099	1	46	1.190	54.762

TABLE II-5. FREQUENCY DISTRIBUTION OF STANDARD DEVIATIONS OF ANALYZED ALKALINITIES - (CONTINUED)

Standard Deviation ($mg/L\ CaCO_3$)	FREQUENCY	CUM FREQ	PERCENT	CUM PERCENT
0.1	3	49	3.571	58.333
0.11	5	54	5.952	64.286
0.12	2	56	2.381	66.667
0.131	1	57	1.190	67.857
0.14	2	59	2.381	70.238
0.16	3	62	3.571	73.810
0.17	2	64	2.381	76.190
0.2	1	65	1.190	77.381
0.204	1	66	1.190	78.571
0.22	3	69	3.571	82.143
0.25	2	71	2.381	84.524
0.27	1	72	1.190	85.714
0.28	1	73	1.190	86.905
0.3	1	74	1.190	88.095
0.33	1	75	1.190	89.286
0.34	1	76	1.190	90.476
0.38	1	77	1.190	91.667
0.41	1	78	1.190	92.857
0.44	1	79	1.190	94.048
0.52	1	80	1.190	95.238
0.58	1	81	1.190	96.429
0.64	1	82	1.190	97.619
0.71	1	83	1.190	98.810
1.2	1	84	1.190	100.000

TABLE II-6. QUALITY CONTROL RESULTS FOR REFERENCE STANDARDS IN POTENTIOMETRIC CHLORIDE TITRATIONS

	USGS 70	USGS 74	EMS1 478-3	EMSL 478-4 (x0.1)	USGS 64 (x0.01)
Reference Value	2.71	1.40	20.8	7.06	2.45
±Standard Deviation	0.84	0.79	0.11	0.44	0.08
True Value	NA	NA	20.5	7.02	NA
Number of Analyses	2	1	21	27	3
Mean Analysis Value	2.6	1.4	20.4	7.00	2.54
Standard Deviation	0.12	-	0.17	0.033	0.015
Coefficient of Variation	4.6	-	0.83	0.47	0.59
Percent Bias	-	-	-0.5	-0.3	-

TABLE II-7. QUALITY CONTROL DATA FOR BLIND UNKNOWNS WITH REFERENCE VALUES FOR SULFATE, FLUORIDE, SILICON AND TOTAL DISSOLVED SOLIDS

Constituent	Reference Value	4250	4998	5461	5460	5559	5579	5554
SO_4	31.1 ± 1.2	30.	31.	31.	31.	31.	31.	31.
F	0.050 ± 0.004	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
TDS	69.8 ± 1.6	73.	68.	74.	70.	75.	77.	78.
Si	0.39 ± 0.077	0.2	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

Constituent	Reference Value	5688	5685	4250	4998	4235	4251
SO_4	31.1 ± 1.2	30.	31.	30.	31.	32.	30.
F	0.050 ± 0.004	<0.1	0.1	<0.1	<0.1	<0.1	0.1
TDS	69.8 ± 1.6	71.	70.	73.	68.	77.	72.
Si	0.39 ± 0.077	0.5	0.5	0.2	<0.5	0.3	0.3

Constituent	Reference Value	5580	5553	5689	5552	5479	5409
SO_4	14.3 ± 2.2	18.	15.	14.	14.	14.	14.
F	0.36 ± 0.07	0.4	0.4	0.4	0.4	0.4	0.3
TDS	70.6 ± 5.6	74.	75.	65.	67.	70.	69.
SPC	103.4 ± 7.1	133.	110.	104.	102.	105.	105.
Si	3.09 ± 0.224	<0.5	3.2	3.1	3.0	3.2	2.7

Constituent	Reference Value	5408	5389
SO_4	14.3 ± 2.2	14.	14.
F	0.36 ± 0.07	0.3	0.2
TDS	70.6 ± 5.6	69.	74.
SPC	103.4 ± 7.1	104.	105.
Si	3.09 ± 0.224	2.7	3.0

	True Value	5562	5578	5580
SO_4	18.8	17.	18.	18.
F	0.43	0.4	0.4	0.4
TDS	69.2	75.	76.	74.

	True Value	5561
SO_4	75.	73.
F	1.7	1.5
TDS	277.	334.
SPC	479.	486.

	True Value	4410	4412
SO_4	11.7	11.	11.
F	0.163	<0.1	<0.1
TDS	42.25	46.	47.

TABLE II-7. QUALITY CONTROL DATA FOR BLIND UNKNOWNS WITH REFERENCE VALUES FOR SULFATE, FLUORIDE, SILICON AND TOTAL DISSOLVED SOLIDS - (CONTINUED)

Constituent	True Value	4256
SO_4	7.2	7.
F	0.43	0.3
TDS	54.	74.
SPC	113.	117.

Constituent	True Value	4999
SO_4	75.	73.
F	1.7	1.5
TDS	277.	325.
SPC	479.	489.

Constituent	Reference Value	4351	4405	4352	4133
SO_4	62.1 ± 2.4	63.	63.	63.	61.
F	0.100 ± 0.008	<0.1	<0.1	<0.1	<0.1
TDS	139.5 ± 3.1	151.	141.	146.	142.
Si	0.78 ± 0.051	<0.5	<0.5	<0.5	0.9

Constituent	Reference Value	4407
SO_4	15.5 ± 0.60	15.
F	0.03 ± 0.002	<0.1
TDS	34.9 ± 0.77	34.
Si	0.194 ± 0.028	<0.5

TABLE II-8. QUALITY CONTROL DATA FOR BLIND UNKNOWNS HAVING REFERENCE VALUES FOR NO_3-N, ORTHOPHOSPHATE-P AND TOTAL-P

Constituent	Reference Value	5460	5461
NO_3-N	3.29 ± 0.52	3.4	3.4
PO_4-P	(≤0.474 ± 0.034)*	0.5	0.5
Tot-P	0.474 ± 0.034	0.29	0.29

		5389	5408	5409	5479
NO_3-N	2.43 ± 0.79	2.8	2.8	2.8	2.3
PO_4-P	(≤0.876 ± 0.037)*	0.88	1.0	1.0	1.0
Tot-P	0.876 ± 0.037	0.60	0.56	0.60	0.55

	True Value	5522	5559	5689	5579	5562	5578
NO_3-N	0.62	0.8	0.7	0.7	0.5	0.5	0.5
PO_4-P	0.062	0.1	0.1	0.1	0.1	0.1	0.1
Tot-P	(≥0.062)*	<0.03	0.04	0.06	0.03	<0.03	<0.03

		5553	5554	5685	5688
NO_3-N	-	<0.3	<0.3	<0.3	<0.3
PO_4-P	(≤0.14)*	0.2	0.2	0.1	0.2
Tot-P	0.14	0.07	0.14	0.13	0.14

		4256	4405	4251
NO_3-N	0.31	0.5	0.5	0.5
PO_4-P	0.031	<0.05	<0.05	0.09
Tot-P	(≥0.031)*	0.10	<0.03	0.10

		4351	4352	4133	4407
NO_3-N	1.59	1.4	1.5	1.2	1.3
PO_4-P	0.154	0.10	0.10	0.18	0.2
Tot-P	(≥0.154)*	0.15	0.13	0.09	<0.03

*Presumed to be this value

TABLE II-8. QUALITY CONTROL DATA FOR BLIND UNKNOWNS HAVING REFERENCE VALUES FOR NO_3-N, ORTHOPHOSPHATE-P AND TOTAL-P (CONTINUED)

Constituent	True Value	4250	4410	4412
NO_3-N	-	<0.3	<0.3	4.0
PO_4-P	(≤0.93)*	0.25	0.8	0.6
Tot-P	0.93	0.93	<0.03	<0.03

		4998	4999
NO_3-N	1.55	1.5	1.5
PO_4-P	0.155	0.15	0.13
Tot-P	(≥0.155)*	ND	ND

	Reference Value	4235
NO_3-N	3.29 ± 0.52	2.6
PO_4-P	(≤0.47 ± 0.034)*	0.50
Tot-P	0.47 ± 0.034	0.50

*Presumed to be this value.

TABLE II-9. QUALITY CONTROL DATA FOR BLIND UNKNOWNS HAVING REFERENCE VALUES FOR TRACE METALS

Constituent	Reference Value(mg/L)			4133	4998	4999	5689	5409
Fe	0.110	±	0.015	0.21	<0.1	0.18	0.24	0.23
Zn	0.0225	±	0.004	<0.02	0.04	0.02	<0.02	0.04
Mn	0.035	±	0.005	0.04	0.04	0.04	0.04	<0.03
Cu	0.0188	±	0.0030	0.04	<0.02	<0.02	<0.02	0.03
Pb	0.0107	±	0.0053	0.009	0.009	0.008	0.005	0.010
Cd	0.0038	±	0.0007	<0.002	0.004	0.004	0.004	0.003
As	0.0025	±	0.001	<0.005	<0.005	<0.005	<0.005	<0.005
Se	0.0046	±	0.0014	<0.005	<0.005	<0.005	<0.005	<0.005
Al	0.490	±	0.117	0.4	0.4	0.3	0.3	0.3
Ba	0.092	±	0.033	<0.2	<0.2	<0.2	<0.2	<0.2
Hg	0.00034	±	0.00012	<0.0005	0.0006	<0.0005	<0.0005	<0.0005

				5688	5479	5552	5553
Fe	0.372	±	0.026	0.43	0.41	0.40	0.42
Zn	0.238	±	0.012	0.22	0.22	0.22	0.23
Mn	0.527	±	0.020	0.56	0.54	0.58	0.56
Cu	0.102	±	0.009	0.10	0.09	0.11	0.10
Pb	0.0165	±	0.0072	0.018	0.014	0.015	0.015
Cd	0.0079	±	0.0012	0.008	0.007	0.005	0.008
As	0.0053	±	0.0018	<0.005	0.009	<0.005	<0.005
Se	0.0070	±	0.0021	<0.005	<0.005	<0.005	<0.005
Al	0.236	±	0.053	0.2	0.2	0.2	0.2
Ba	0.030	±	0.027	<0.2	<0.2	<0.2	<0.2
Hg	0.0156	±	0.0025	0.0052	0.0078	0.0072	0.0152

TABLE II-9. QUALITY CONTROL DATA FOR BLIND UNKNOWNS HAVING REFERENCE VALUES FOR TRACE METALS - (CONTINUED)

Constituent	Reference Value(mg/L)			5554	5559	5685	5389
Fe	0.766	±	0.035	0.81	0.86	0.77	0.82
Zn	0.0134	±	0.0047	<0.02	<0.02	<0.02	0.02
Mn	0.563	±	0.039	0.62	0.56	0.61	0.58
Cu	0.025	±	0.0042	0.06	0.03	0.02	0.03
Pb	0.003	±	0.0013	0.005	0.008	<0.005	<0.005
Cd	0.0101	±	0.0027	0.008	0.008	0.003	0.008
As	0.0177	±	0.0027	<0.005	0.017	0.015	0.013
Se	0.0124	±	0.0014	0.009	<0.005	0.009	0.010
Al	0.023	±	0.017	<0.1	<0.1	<0.1	<0.1
Ba	0.233	±	0.040	<0.2	0.20	0.21	<0.2
Hg	0.00196	±	0.00040	0.0032	<0.0005	0.0016	0.0035
				4235	4351	5352	4405
Fe	0.134	±	0.015	0.12	0.20	0.21	0.14
Zn	0.252	±	0.019	0.24	0.23	0.23	0.25
Mn	0.341	±	0.022	0.36	0.38	0.38	0.52
Cu	0.0626	±	0.0065	0.07	0.06	0.08	0.06
Pb	0.0165	±	0.0164	<0.005	0.005	0.005	0.006
Cd	0.0159	±	0.0032	0.014	0.009	0.009	0.011
As	0.0342	±	0.0088	0.038	0.036	0.036	0.047
Se	0.0057	±	0.0022	0.005	<0.005	<0.005	<0.005
Al	0.235	±	0.201	0.2	0.2	0.3	0.2
Ba	0.203	±	0.084	<0.2	0.26	0.8	0.2
Hg	0.00345	±	0.00024	0.0042	0.008	0.0185	0.005

TABLE II-9. QUALITY CONTROL DATA FOR BLIND UNKNOWNS HAVING REFERENCE VALUES FOR TRACE METALS - (CONTINUED)

Constituent	True Value(mg/L)	4250
Fe	0.398	0.39
Zn	0.239	0.24
Mn	0.239	0.24
Cu	0.187	0.22
Pb	0.192	0.205
Cd	0.030	0.018
As	0.091	0.095
Se	0.024	0.024
Al	0.426	0.3
Hg	0.0038	0.0035 (inors) 0.006 (tot)

		5460	5461	5578
Fe	.078	<0.1	<0.1	<0.1
Zn	0.026	<0.2	<0.2	0.03
Mn	.047	0.04	0.05	0.04
Cu	.037	0.03	0.04	0.02
Pb	.113	.116	.124	0.120
Cd	.027	0.018	0.018	0.014
As	.061	0.059	0.060	0.053
Se	0.0160	0.017	0.018	0.015
Al	.435	0.4	0.4	0.3
Hg	0.00344	<0.0005	0.0023	0.0032

TABLE II-9. QUALITY CONTROL DATA FOR BLIND UNKNOWNS
HAVING REFERENCE VALUES FOR TRACE METALS - (CONTINUED)

Constituent	True Value(mg/L)	5562	5579
Fe	0.016	<0.1	<0.1
Zn	0.006	<0.02	<0.02
Mn	0.0079	<0.03	<0.03
Cu	0.0087	<0.02	0.03
Pb	0.030	0.031	0.028
Cd	0.0065	0.007	0.008
As	0.024	0.022	<0.005
Se	0.0087	<0.005	0.008
Al	0.061	0.1	0.1
Hg	0.0004	<0.0005	<0.0005

TABLE II-10. QUALITY CONTROL DATA FOR BLIND UNKNOWNS HAVING REFERENCE VALUES FOR CALCIUM, MAGNESIUM, SODIUM AND POTASSIUM

Constituent	True Value(mg/L)		
		4256	
Ca	5.3	4.8	
Mg	1.8	1.67	
Na	8.2	8.4	
K	2.1	2.0	
		4410	4412
Ca	5.08	4.8	4.9
Mg	1.05	1.07	0.99
Na	5.83	6.6	6.8
K	1.23	1.2	1.2
	Reference Value(mg/L)		4407
Ca	4.15 ± 0.15		4.1
Mg	1.615 ± 0.040		1.6
Na	4.00 ± 0.100		4.0
K	0.207 ± 0.025		0.2
			4251
Ca	8.3 ± 0.30		8.0
Mg	3.23 ± 0.22		2.93
Na	8.00 ± 0.20		8.4
K	0.41 ± 0.050		0.4

TABLE II-11. QUALITY CONTROL DATA FOR BLIND UNKNOWNS HAVING REFERENCE VALUES FOR A VARIETY OF MINERAL CONSTITUENTS

Constituent	True Value	
		5580
TDS	69.3	74.
Ca	8.0	7.6
Mg	1.78	1.69
Na	10.0	9.9
K	1.8	1.8
Cl^-	17.6	17.7
F^-	0.4	0.4
SO_4	18.8	18.

TABLE II-12. FIELD DUPLICATE SAMPLES

	64240	64236	53475	53467	53476	53468
Ca	20.4	22.6	28.0	29.2	28.2	29.7
Mg	1.57	1.59	5.48	5.64	5.65	5.55
Na	12.1	12.2	8.9	9.1	8.9	9.3
K	1.4	1.4	0.6	0.6	0.6	0.6
Alk (CAEP)	16.0	15.7	83.8	84.2	70.6	70.7
SO_4	32.	35.	11.	11.	26.	25.
Cl	20	20.	<10*,13.4	<10*,13.2	<10*,14.1	<10*,14.0
F	0.5	0.5	<0.1	<0.1	<0.1	<0.1
NO_3-N	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
PO_4-P	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Tot-P	<0.03	<0.03	<0.05	<0.05	<0.05	<0.05
Si	1.6	1.5	2.4	2.3	1.9	1.8
Fe	0.11	<0.1	0.24	0.15	<0.1	<0.1
Zn	<0.02	0.03	<0.02	<0.002	<0.02	<0.02
Mn	<0.03	<0.03	0.05	0.04	<0.03	<0.03
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cu	0.32	0.27	0.08	0.08	<0.02	0.02
Pb	0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Se	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
As	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Al	<0.1	<0.1	<0.1	<0.1	0.3	0.2
Ba	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Hg	<0.0005	<0.0005	<0.0005	<0.005	<0.0005	<0.0005
SPC	220.	220.	---	---	---	---
TDS	132.	130.	143.	137.	148.	142.
Color	2.	3.	3.	4.	2.	2.

*Colorimetric determination

TABLE II-12. FIELD DUPLICATE SAMPLES - (CONTINUED)

	63953	63968	63504	63521	63503	63520
Ca	2.4	2.6	3.4	3.2	3.2	3.5
Mg	1.08	1.09	0.79	0.86	0.84	0.79
Na	5.0	5.2	10.4	10.5	6.2	7.3
K	0.7	0.7	0.7	0.7	0.6	0.7
Alk (CAEP)			13.2	13.0	5.7	5.9
SO_4			5.	6.	5.	6.
Cl			<10*,12.1	<10*,12.1	<10*,10.9	<10*,10.8
F			1.0	1.0	<0.1	<0.1
NO_3-N			<0.3	<0.3	<0.3	<0.3
PO_4-P			<0.05	<0.05	<0.05	<0.05
Tot-P			<0.03	<0.03	0.05	<0.03
Si			1.2	1.2	0.9	0.8
Fe	0.11	0.11	<0.1	<0.1	<0.1	<0.1
Zn	<0.02	<0.02	<0.02	0.03	<0.02	<0.02
Mn	0.04	0.04	<0.03	0.04	<0.03	<0.03
Cd	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cu	<0.02	<0.02	<0.02	<0.02	0.02	0.02
Pb	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Se	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
As	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Al	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ba	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Hg	<0.0005	<0.0005	<0.0005	<0.005	<0.0005	<0.0005
SPC			95.	95.	70.	70.
TDS			50.	52.	39.	41.
Color			2.	2.	3.	3.

*Colorimetric determination

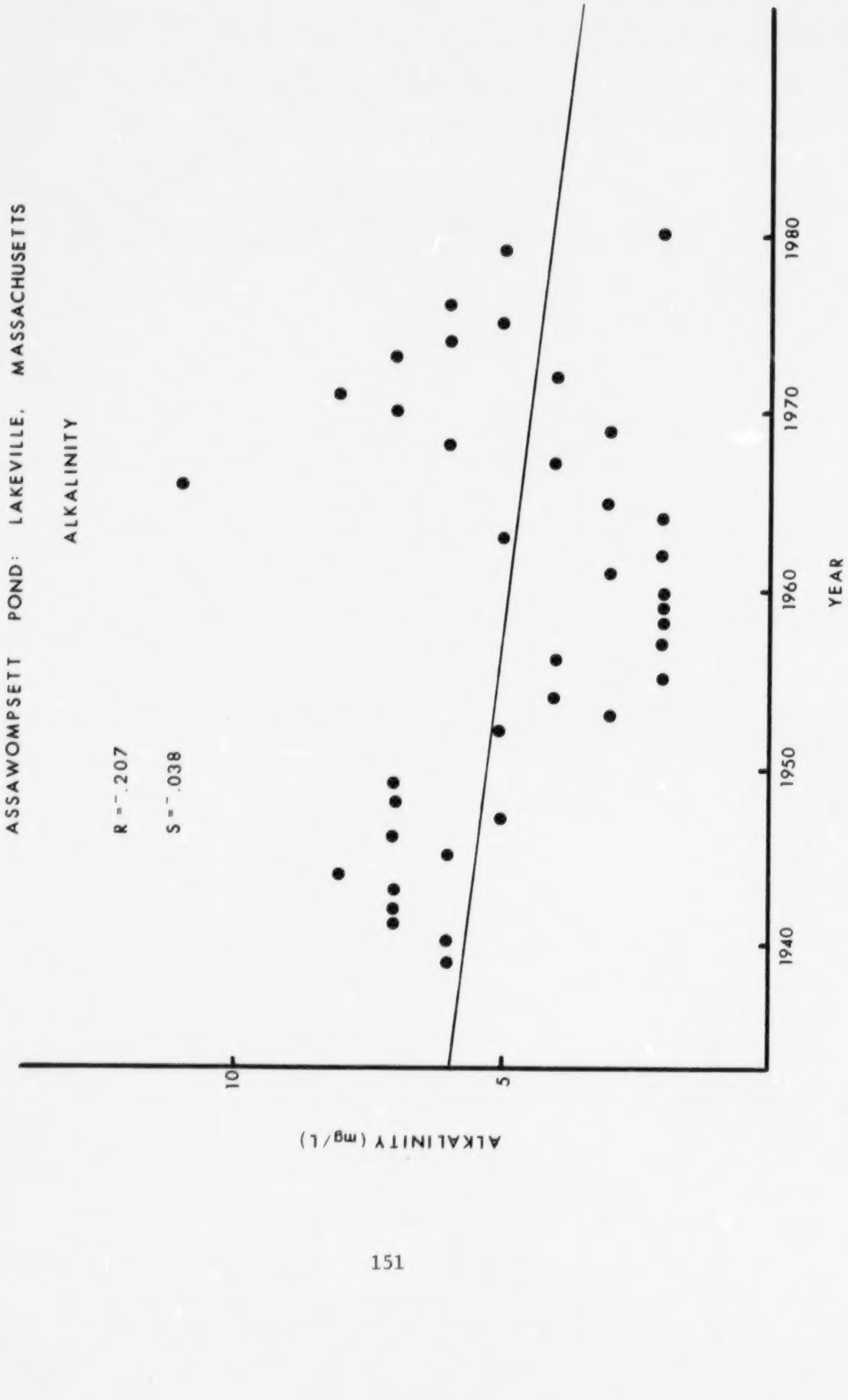
TABLE II-13. CALIBRATION LIMITS FOR ANALYTICAL METHODS USED IN THIS STUDY

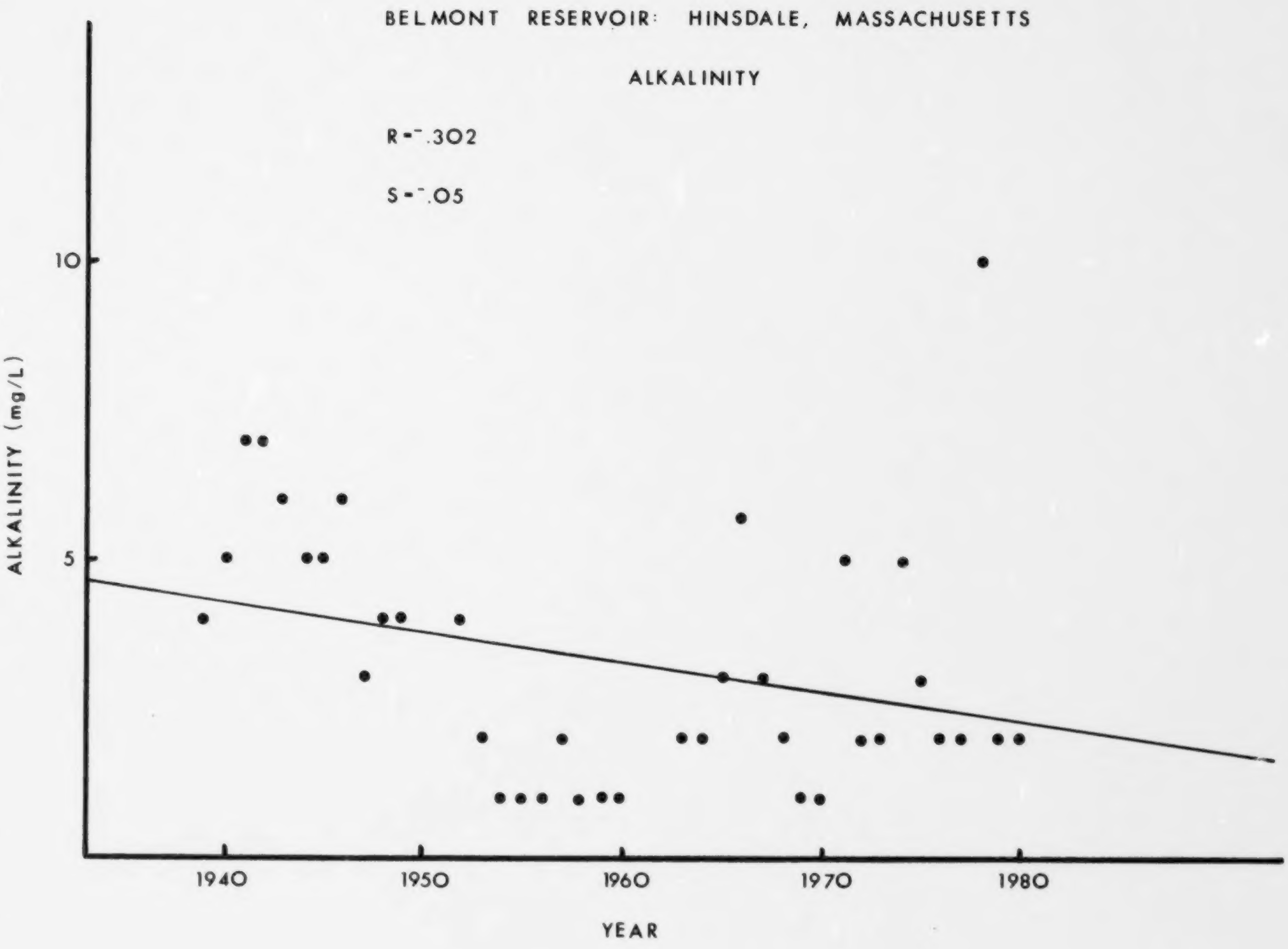
Constituent/Method	Calibration Limit mg/L
Alkalinity (CAEP), as $CaCO_3$	~0.1
Cl (potentiometric)	0.1
Cl (colorimetric)	10.
SO_4	1.
NO_3-N	0.3
Na	1.0
Ba	0.2
As	0.005
Se	0.005
F	0.1
Si	0.5
Al	0.1
K	0.1
PO_4-P	0.05
Total-P	0.03
Ca	0.5
Mg	0.1
Cu	0.02
Mn	0.03
Pb	0.005
Fe	0.1
Cd	0.002
Zn	0.02
Hg	0.0005

APPENDIX III

TRENDS OF ALKALINITY (as $CaCO_3$) VS. TIME FOR RAW WATERS IN MASSACHUSETTS

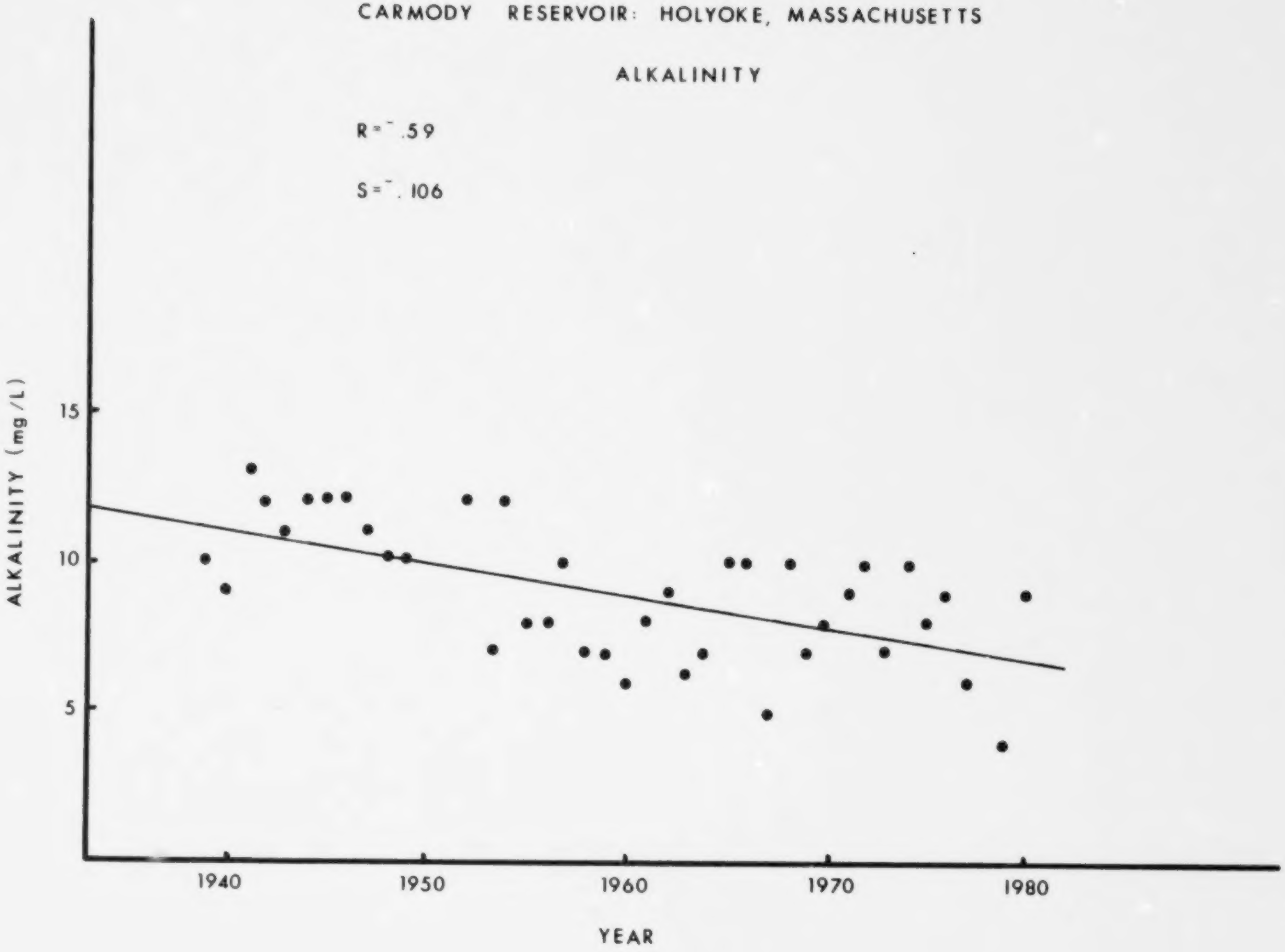
(Figures presented in alphabetical order, by source name)


ASSAWOMPSETT POND: LAKEVILLE, MASSACHUSETTS
ALKALINITY
R = -.207
S = -.038
ALKALINITY (mg/L)
10
5
YEAR
1940
1950
1960
1970
1980



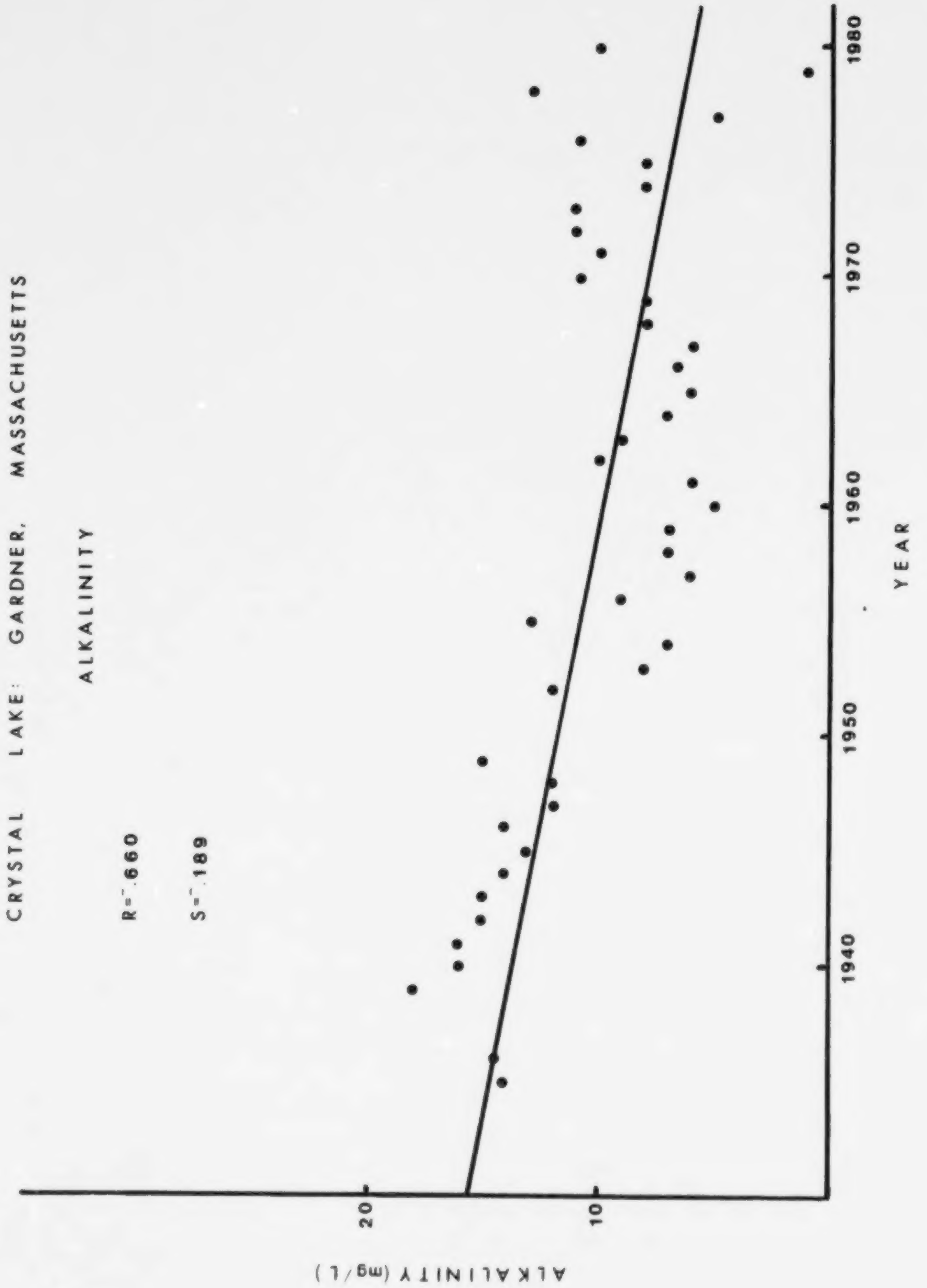
BELMONT RESERVOIR: HINSDALE, MASSACHUSETTS

ALKALINITY



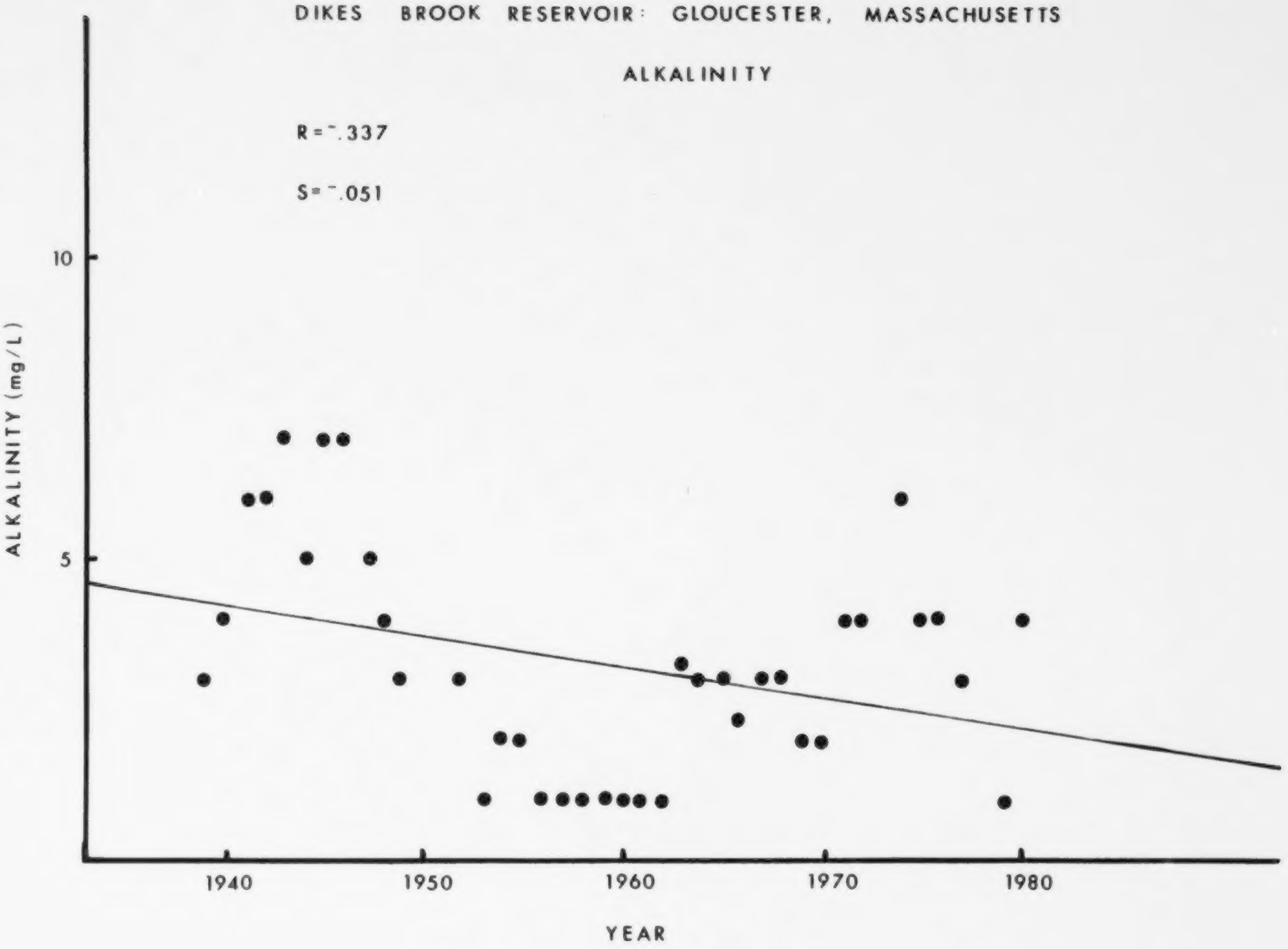
CARMODY RESERVOIR: HOLYOKE, MASSACHUSETTS

ALKALINITY



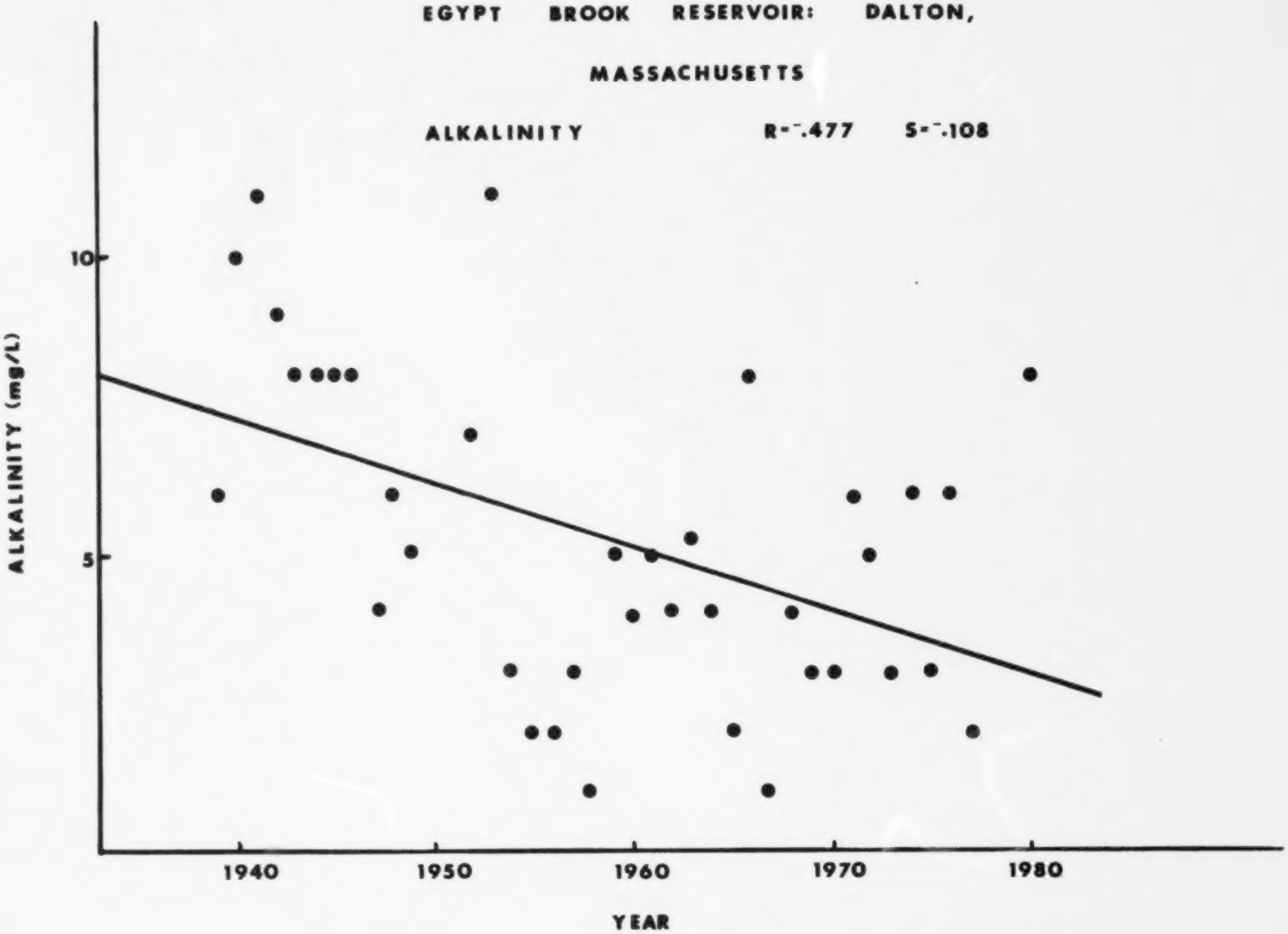
CRYSTAL LAKE: GARDNER, MASSACHUSETTS

ALKALINITY



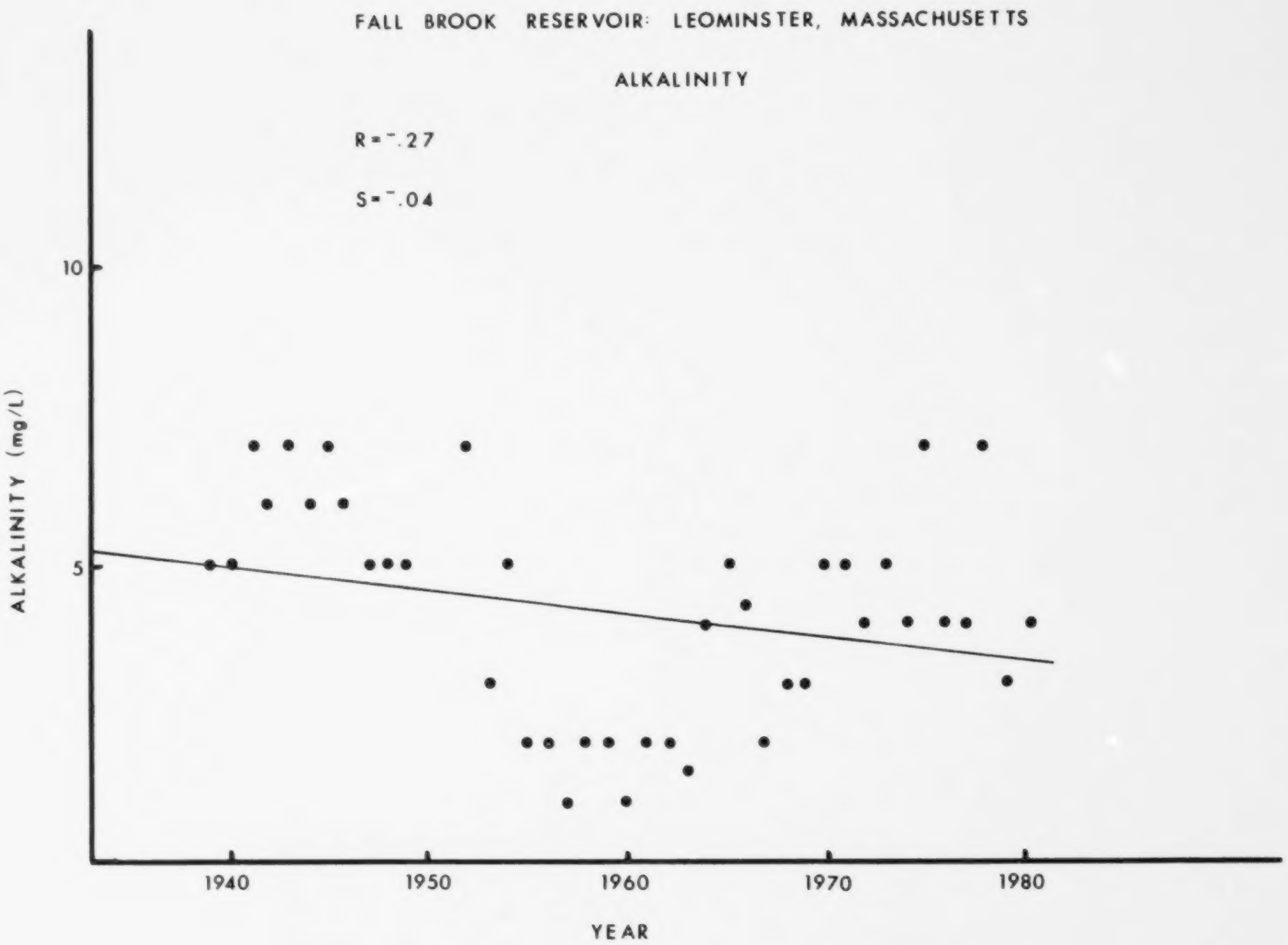
DIKES BROOK RESERVOIR: GLOUCESTER, MASSACHUSETTS

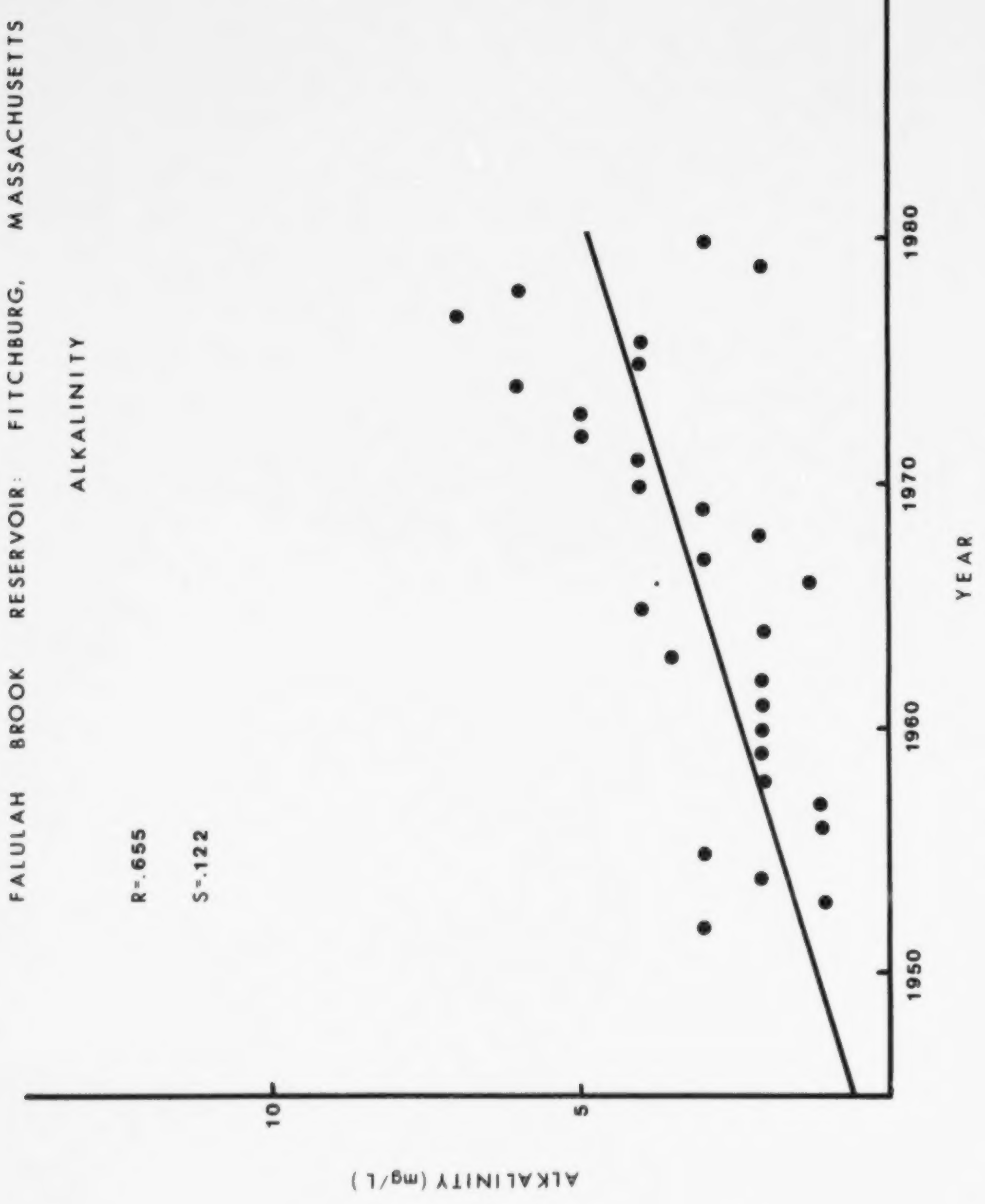
ALKALINITY



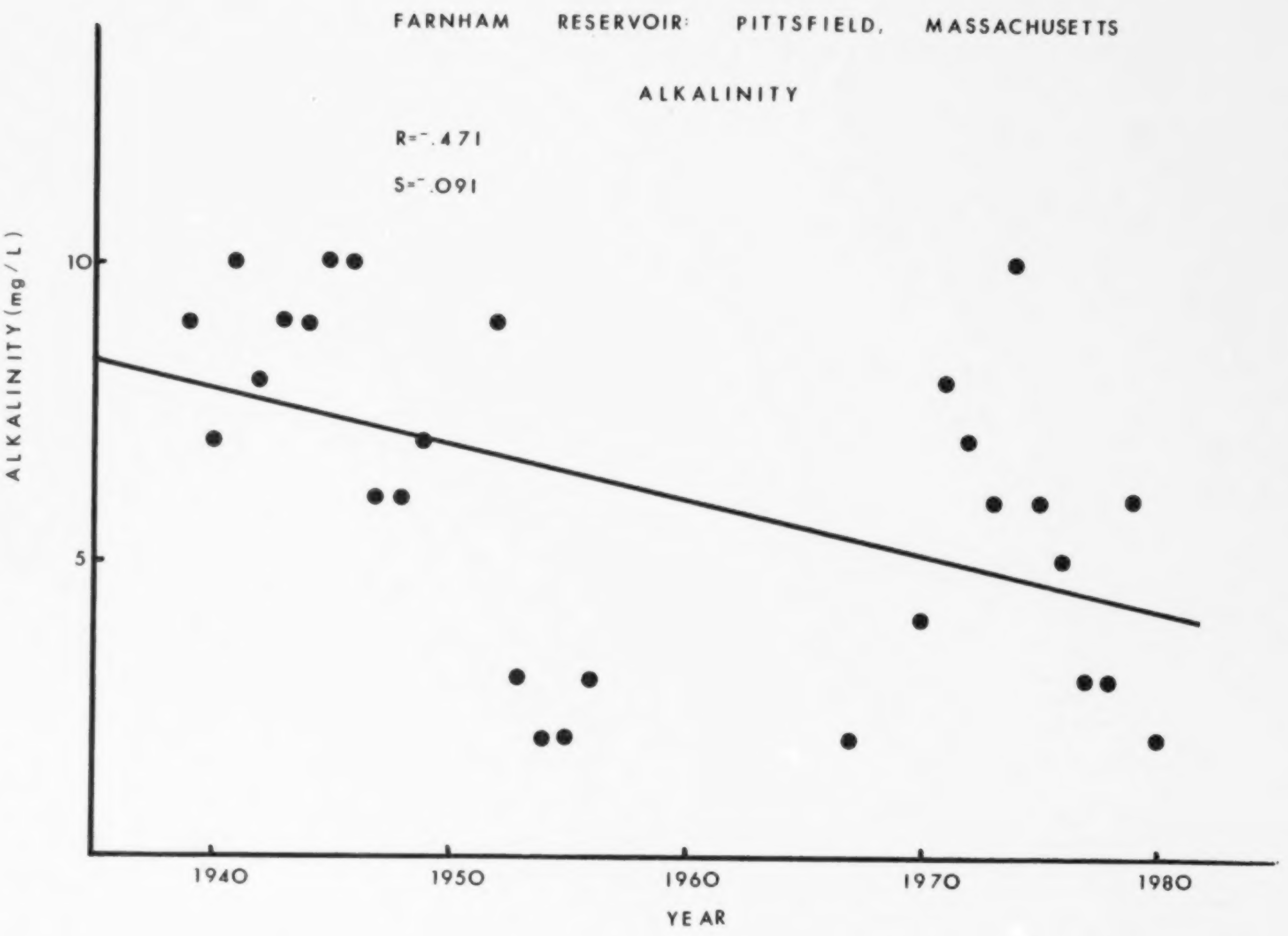
EGYPT BROOK RESERVOIR: DALTON, MASSACHUSETTS

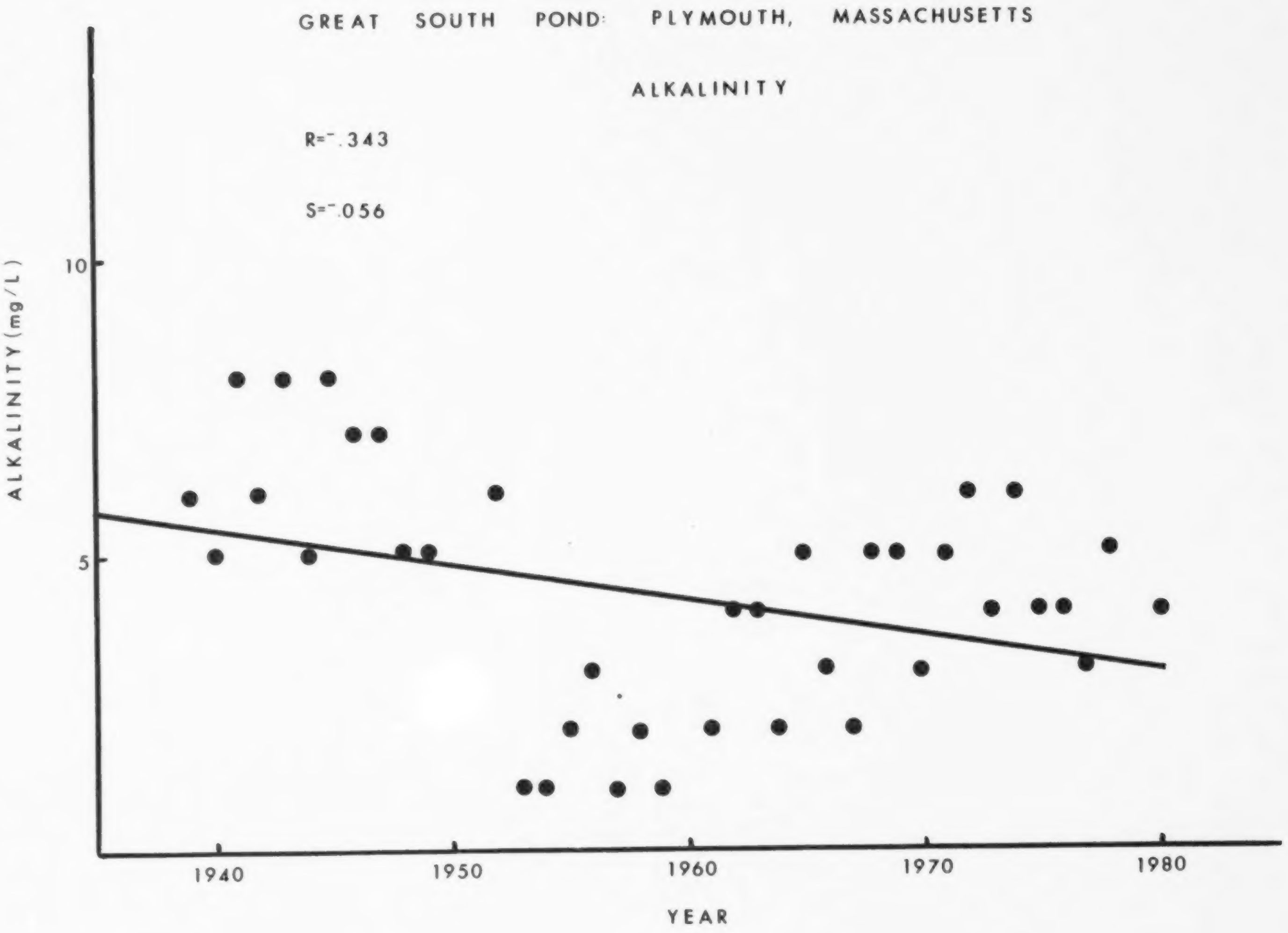
ALKALINITY R=-.477 S=-.108


FALL BROOK RESERVOIR: LEOMINSTER, MASSACHUSETTS
ALKALINITY
R=⁻.27
S=⁻.04
10
5
ALKALINITY (mg/L)
1940
1950
1960
1970
1980
YEAR


FALULAH BROOK RESERVOIR: FITCHBURG, MASSACHUSETTS

ALKALINITY

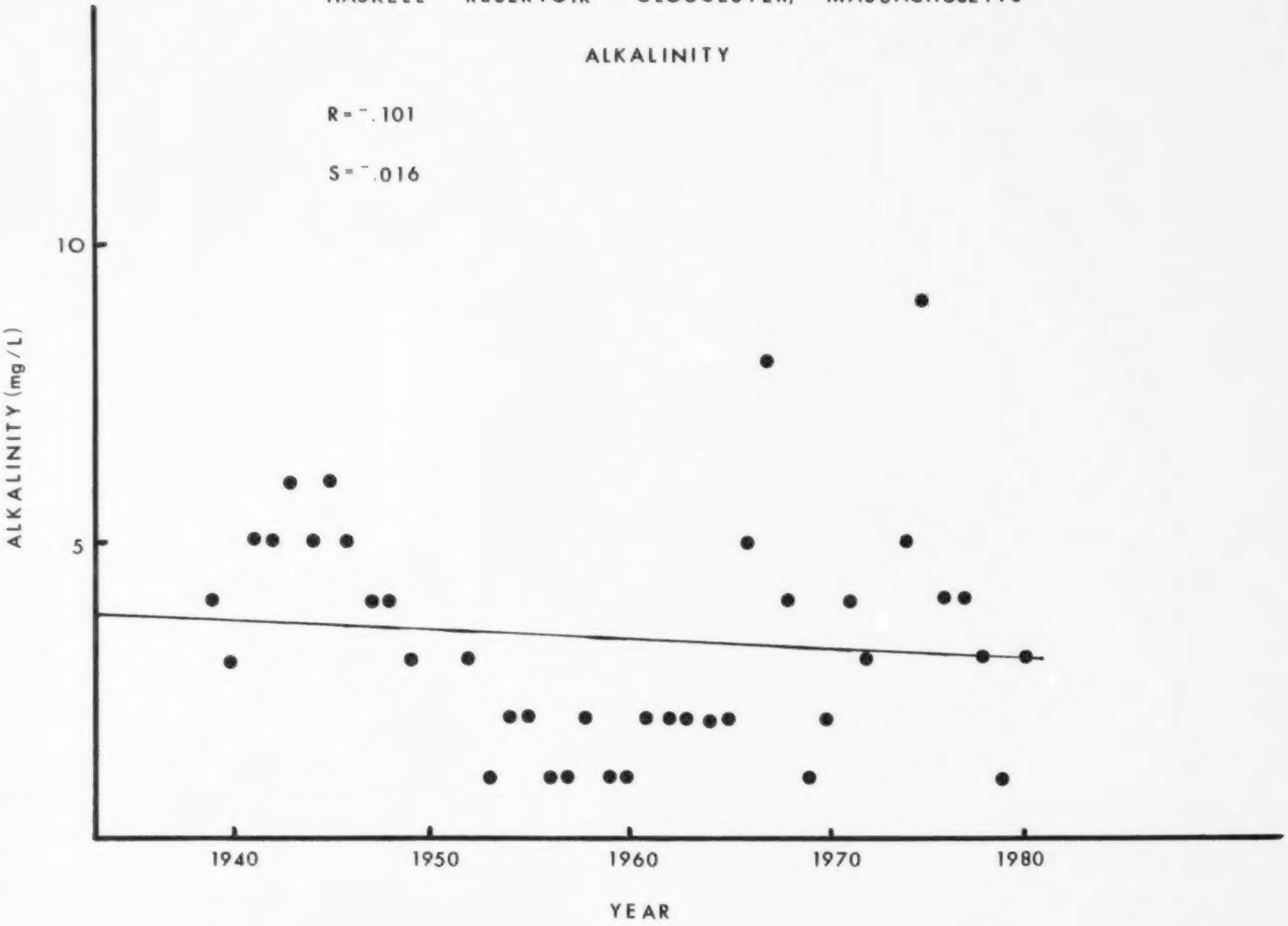

FARNHAM RESERVOIR: PITTSFIELD, MASSACHUSETTS
ALKALINITY
R=⁻.471
S=⁻.091
ALKALINITY (mg/L)
10
5
1940
1950
1960
1970
1980
YEAR


GREAT SOUTH POND: PLYMOUTH, MASSACHUSETTS

ALKALINITY

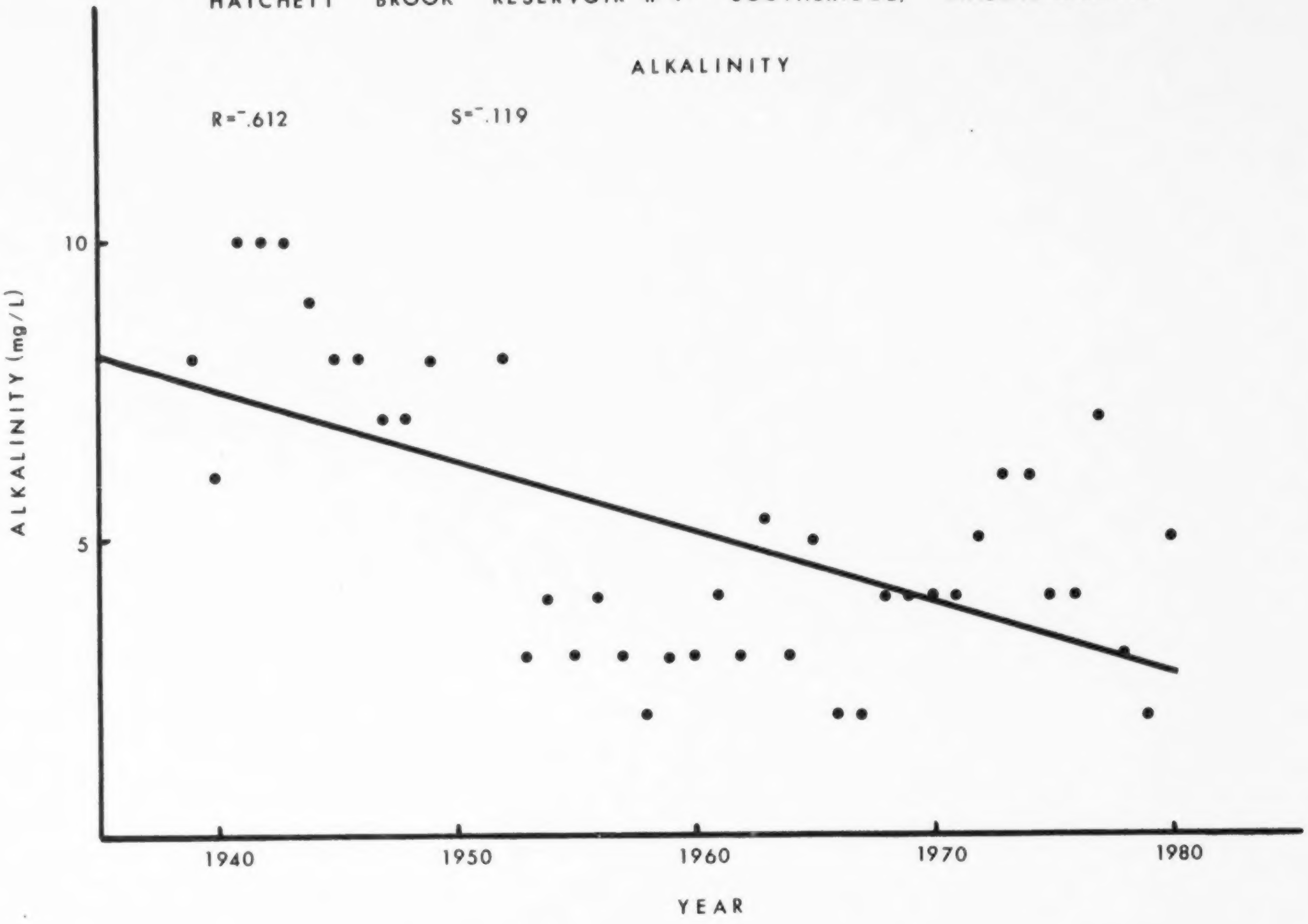
HASKELL RESERVOIR: GLOUCESTER, MASSACHUSETTS

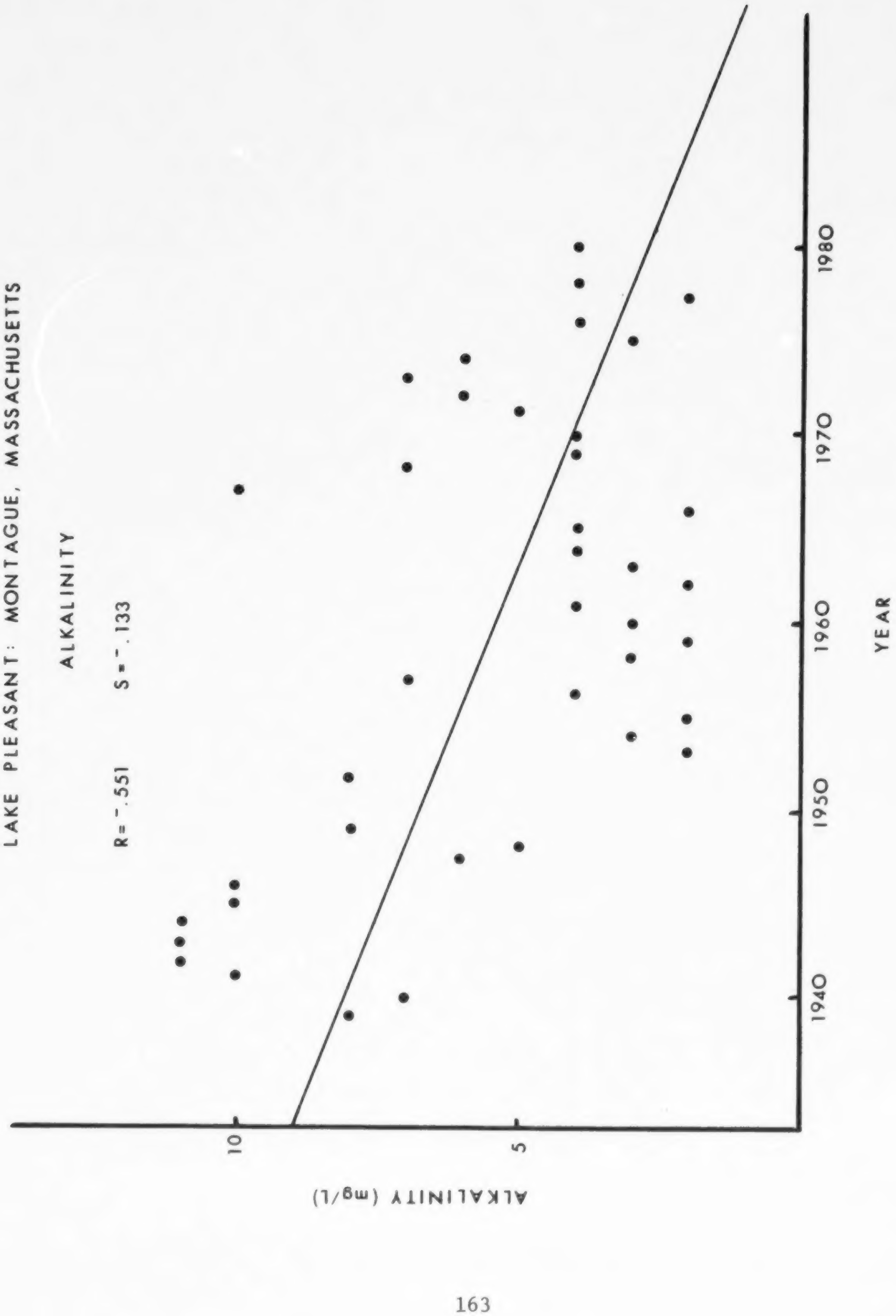
ALKALINITY

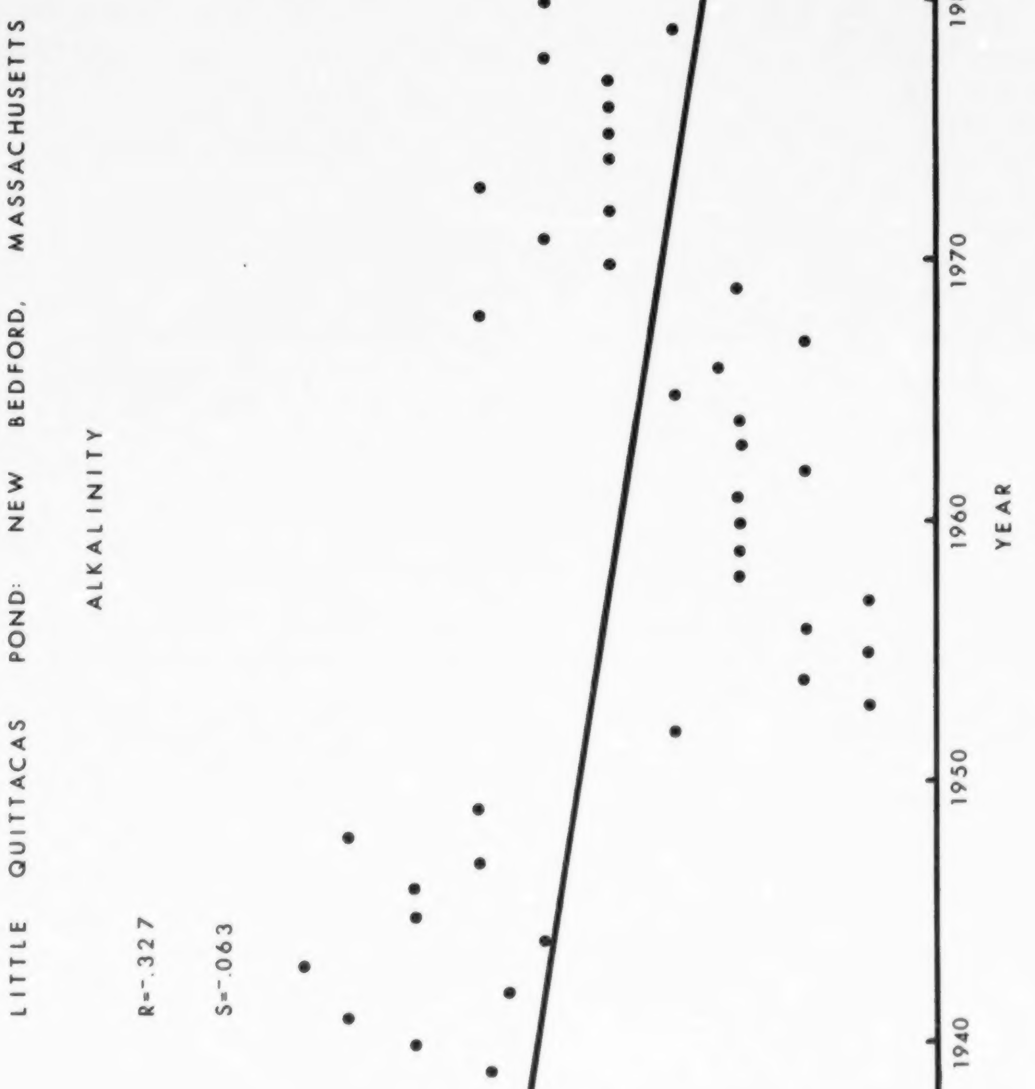


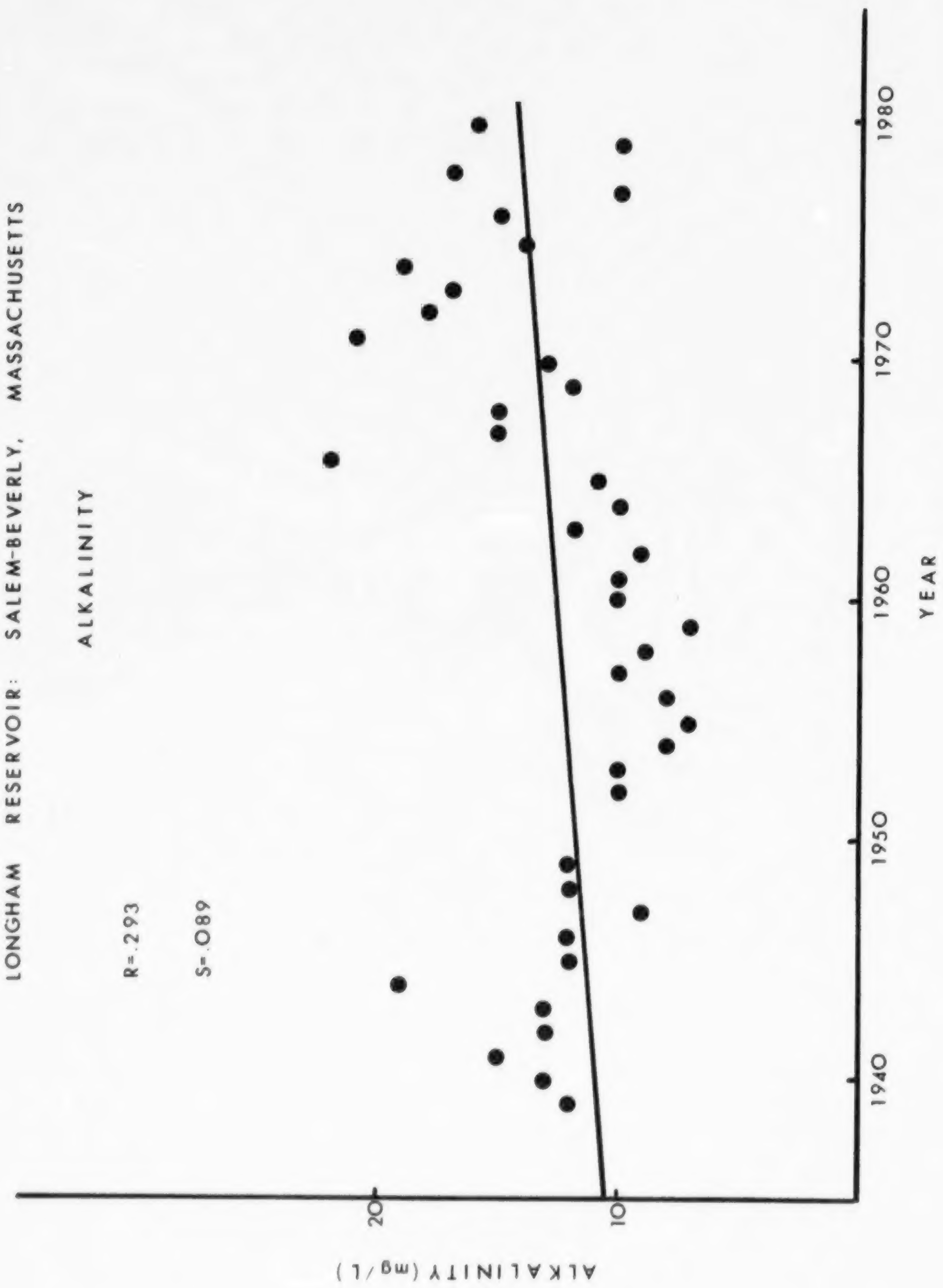
HATCHETT BROOK RESERVOIR # 4: SOUTHBRIDGE, MASSACHUSETTS

ALKALINITY



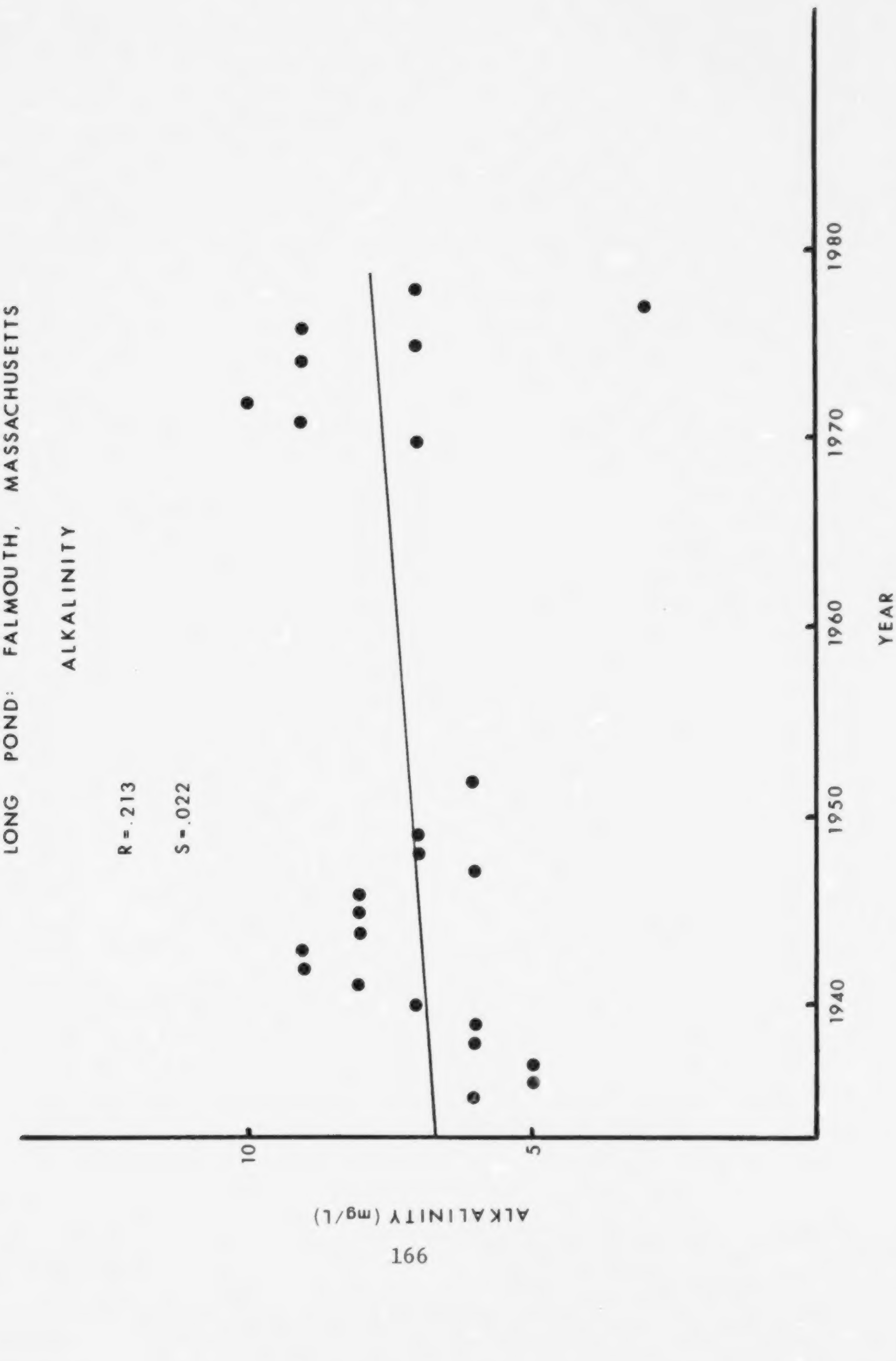

LAKE PLEASANT: MONTAGUE, MASSACHUSETTS
ALKALINITY
R = −.551
S = −.133
ALKALINITY (mg/L)
10
5
1940
1950
1960
1970
1980
YEAR

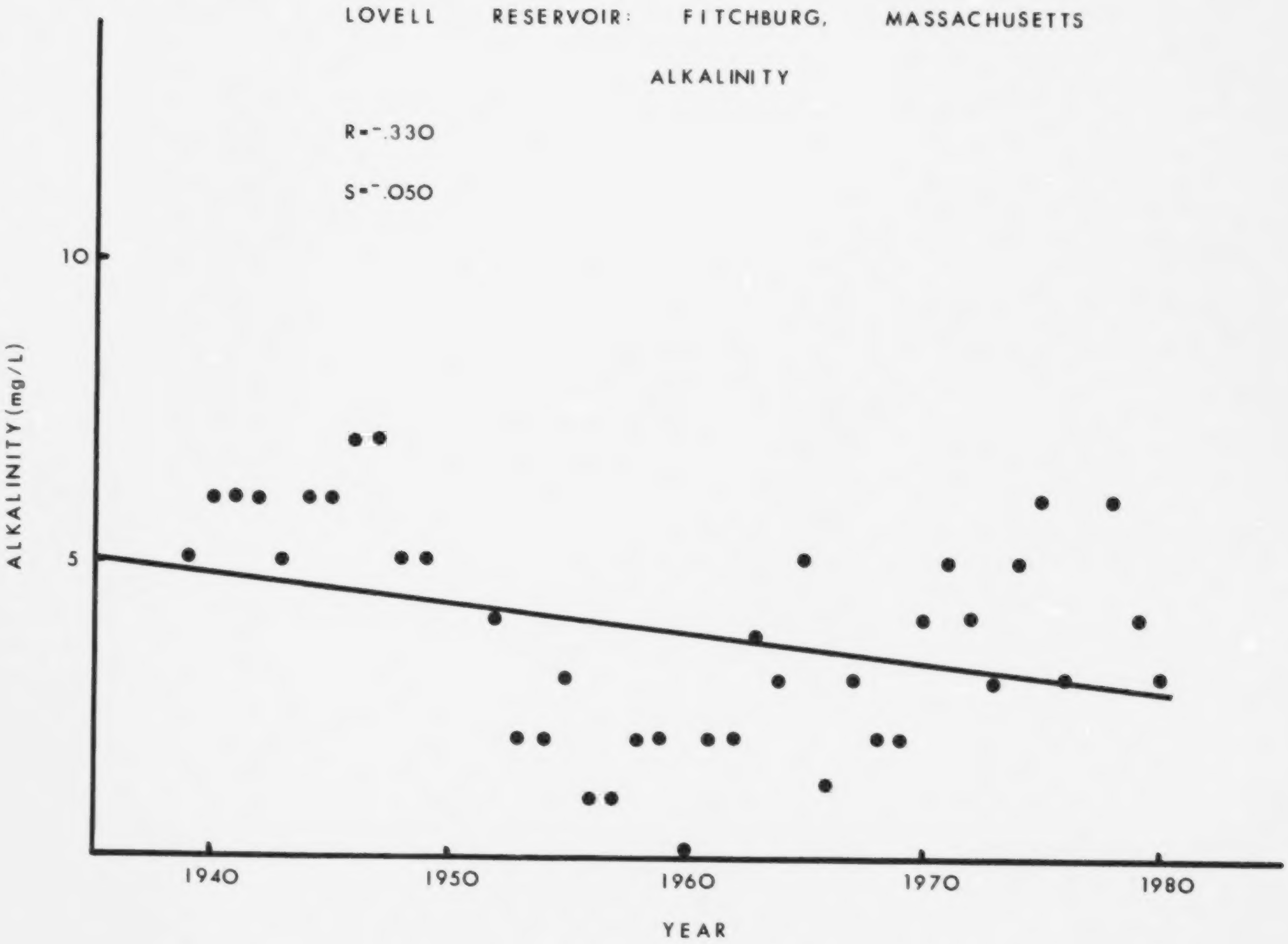

LITTLE QUITTACAS POND: NEW BEDFORD, MASSACHUSETTS
ALKALINITY
R=-.327
S=-.063
ALKALINITY (mg/L)
10
5
1940
1950
1960
1970
1980
YEAR

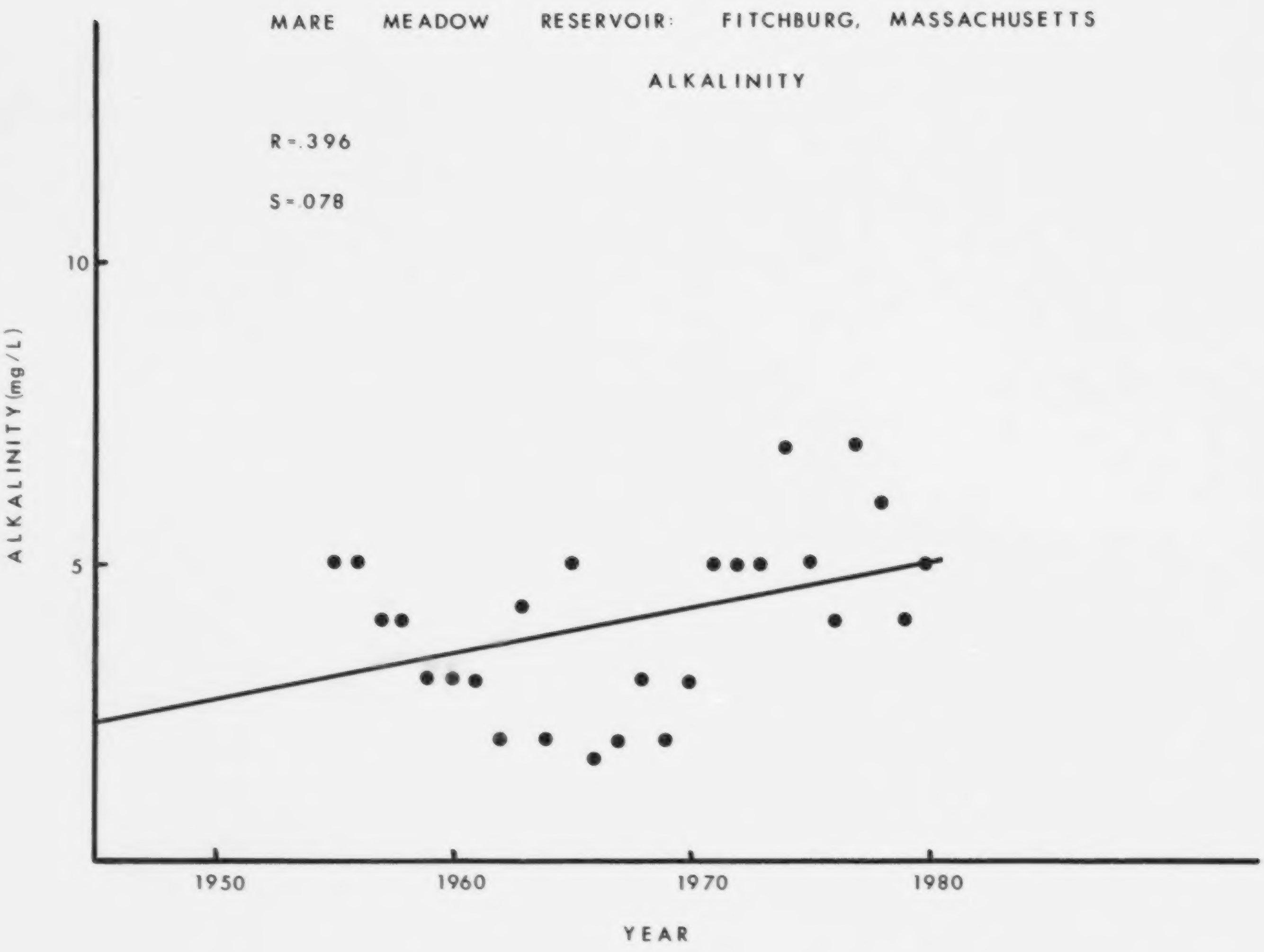


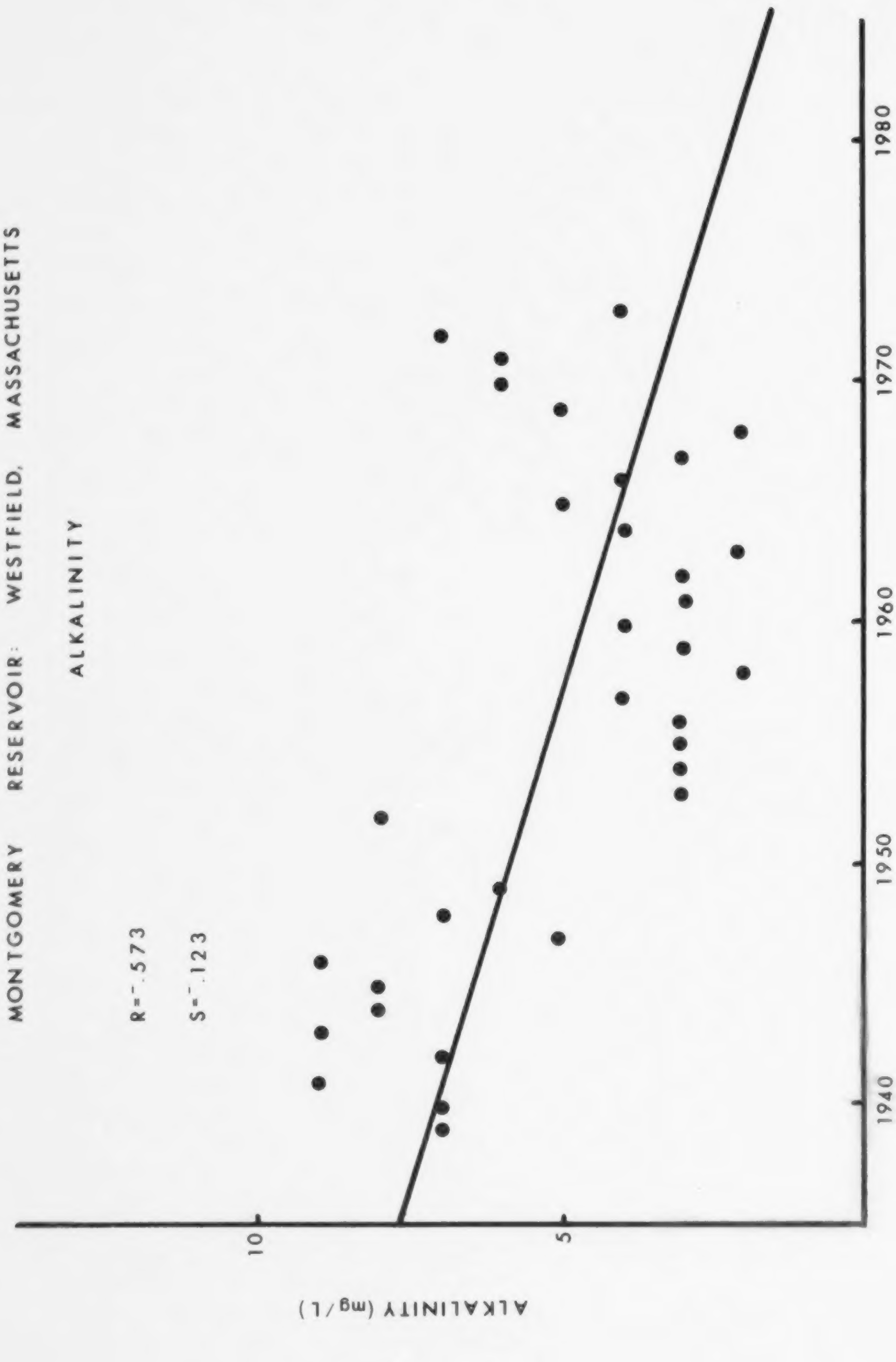
LONGHAM RESERVOIR: SALEM-BEVERLY, MASSACHUSETTS

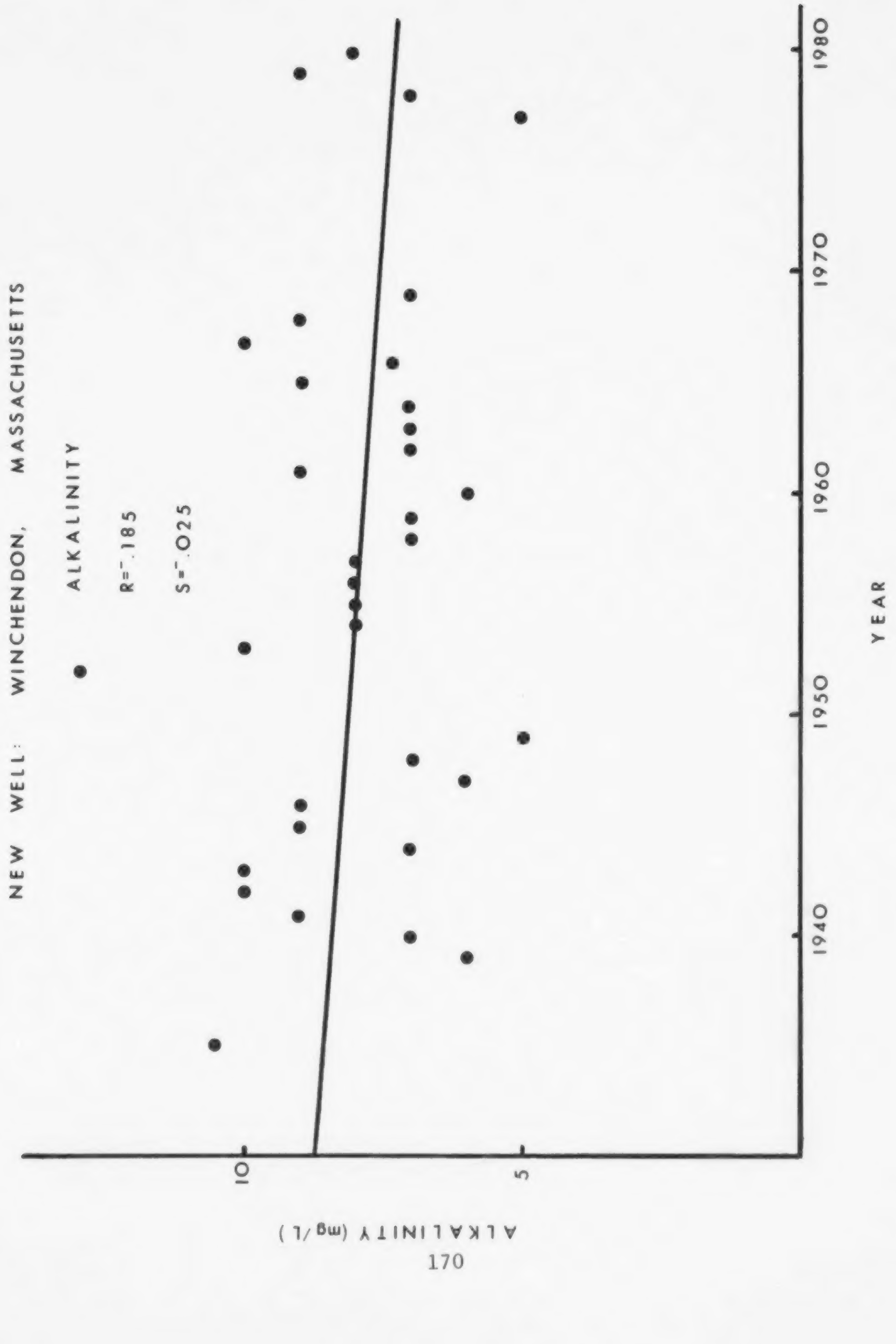
ALKALINITY

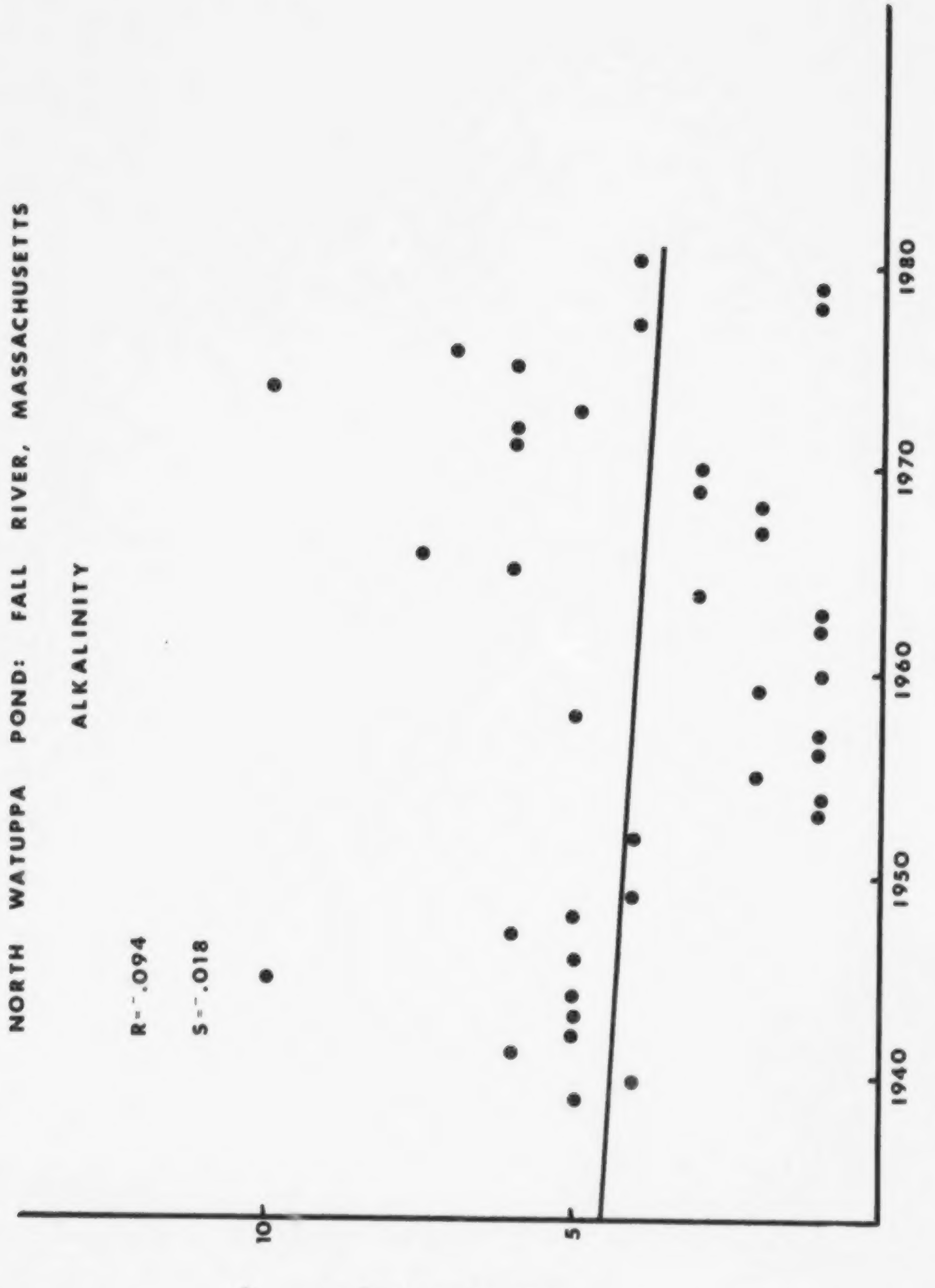

LONG POND: FALMOUTH, MASSACHUSETTS
ALKALINITY
R = .213
S = .022
ALKALINITY (mg/L)
10
5
1940
1950
1960
1970
1980
YEAR

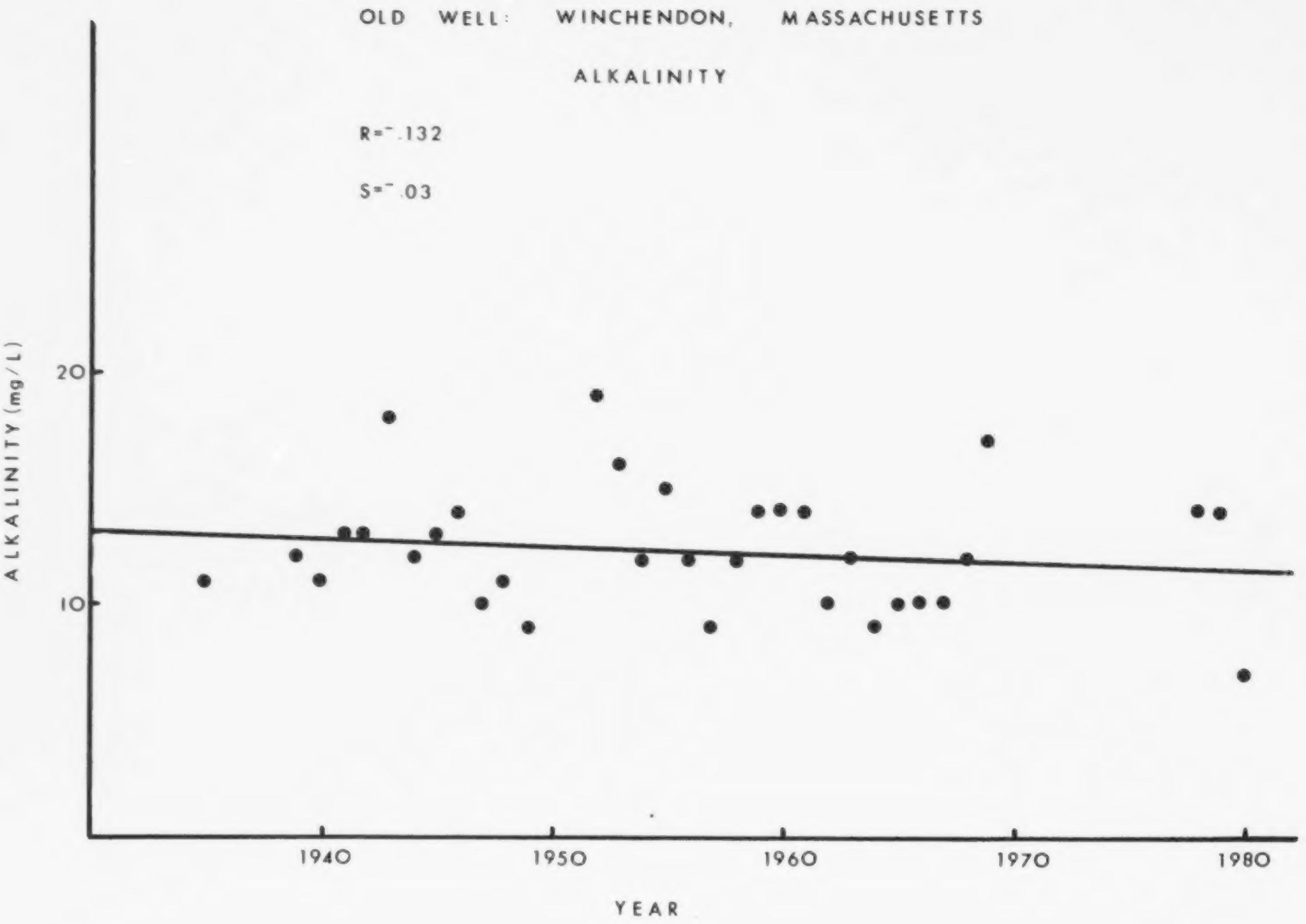

LOVELL RESERVOIR: FITCHBURG, MASSACHUSETTS
ALKALINITY
R=-.330
S=-.050
10
5
ALKALINITY (mg/L)
1940
1950
1960
1970
1980
YEAR

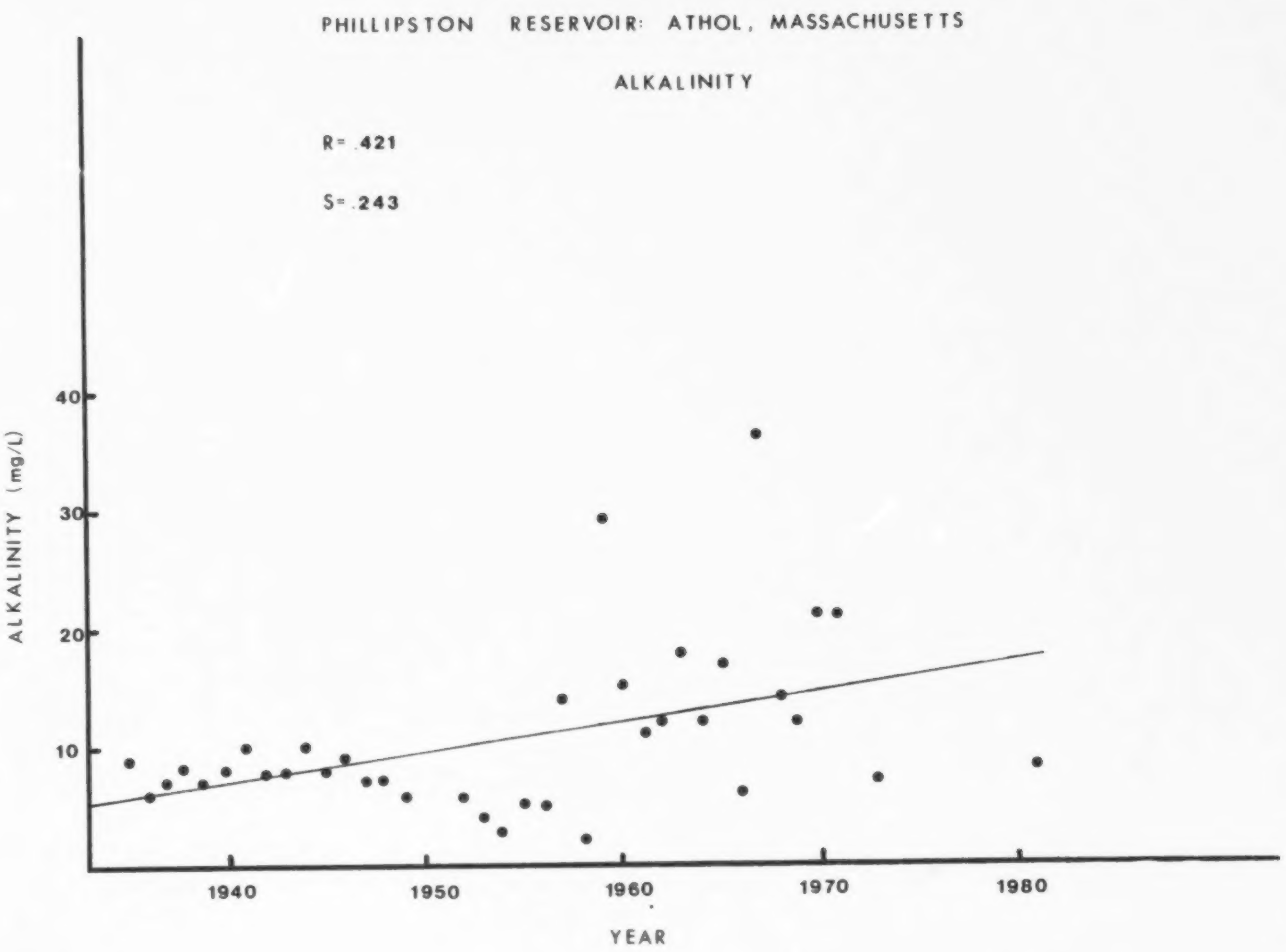

MARE MEADOW RESERVOIR: FITCHBURG, MASSACHUSETTS
ALKALINITY
R=.396
S=.078
10
5
ALKALINITY (mg/L)
1950
1960
1970
1980
YEAR


MONTGOMERY RESERVOIR: WESTFIELD, MASSACHUSETTS
ALKALINITY
R=-.573
S=-.123
10
5
ALKALINITY (mg/L)
1940
1950
1960
1970
1980
YEAR


NEW WELL: WINCHENDON, MASSACHUSETTS
ALKALINITY
R=-.185
S=-.025
ALKALINITY (mg/L)
10
5
YEAR
1940
1950
1960
1970
1980


NORTH WATUPPA POND: FALL RIVER, MASSACHUSETTS
ALKALINITY
R=⁻.094
S=⁻.018
ALKALINITY (mg/L)
10
5
YEAR
1940
1950
1960
1970
1980


OLD WELL: WINCHENDON, MASSACHUSETTS
ALKALINITY
R=⁻.132
S=⁻.03
ALKALINITY (mg/L)
20
10
1940
1950
1960
1970
1980
YEAR

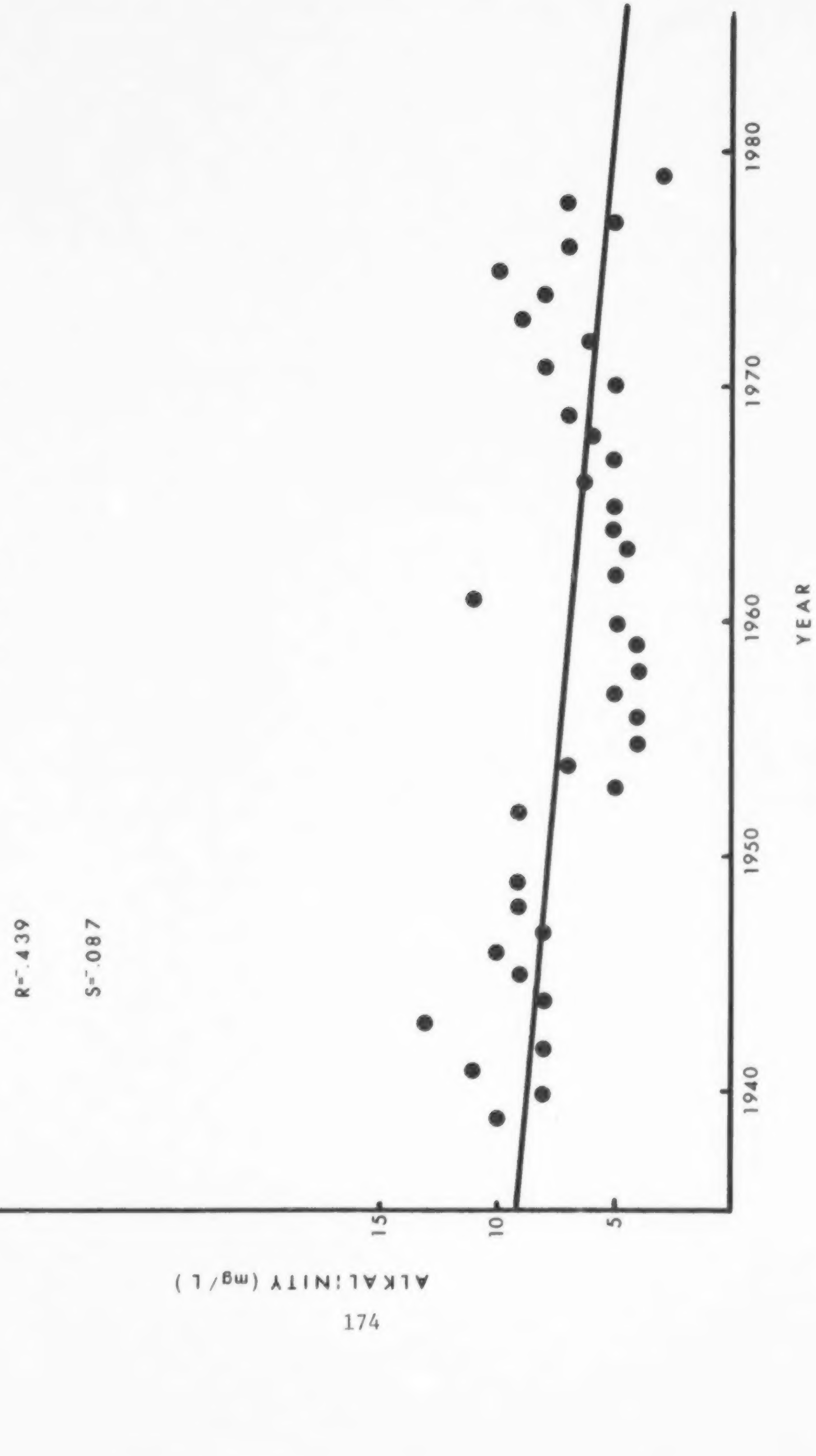


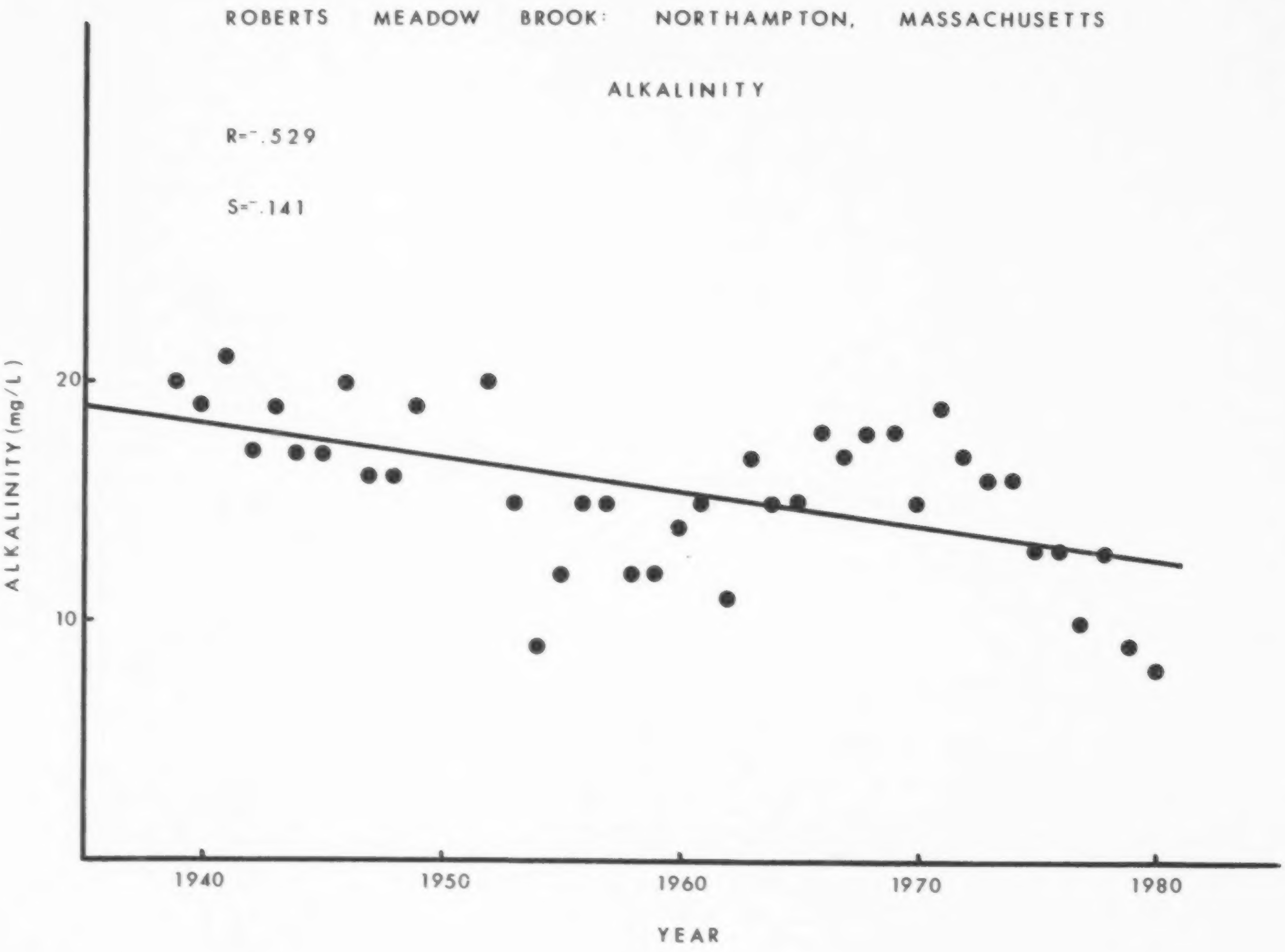
PHILLIPSTON RESERVOIR: ATHOL, MASSACHUSETTS

ALKALINITY

PINE HILL RESERVOIR: WORCESTER, MASSACHUSETTS

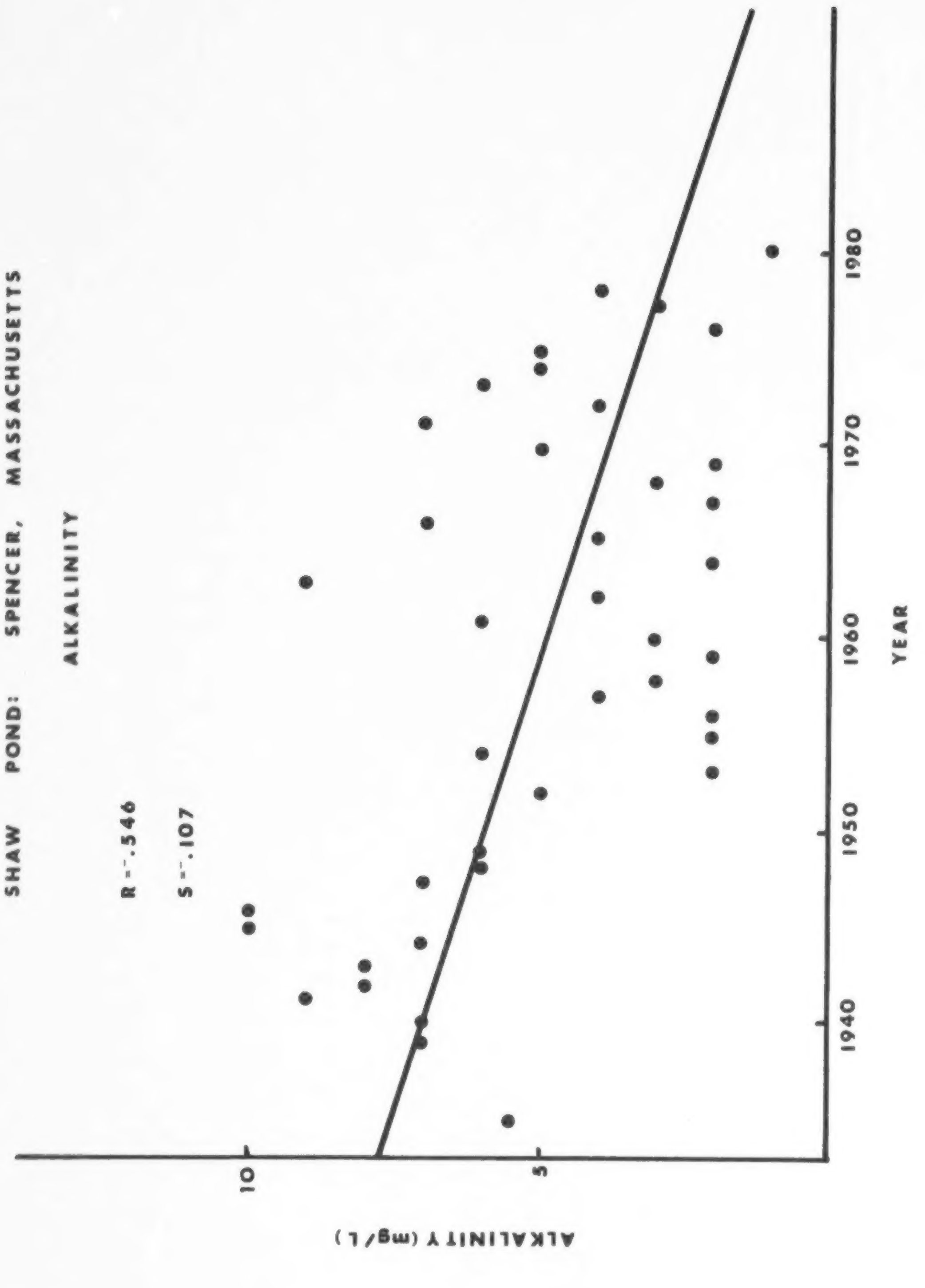
ALKALINITY

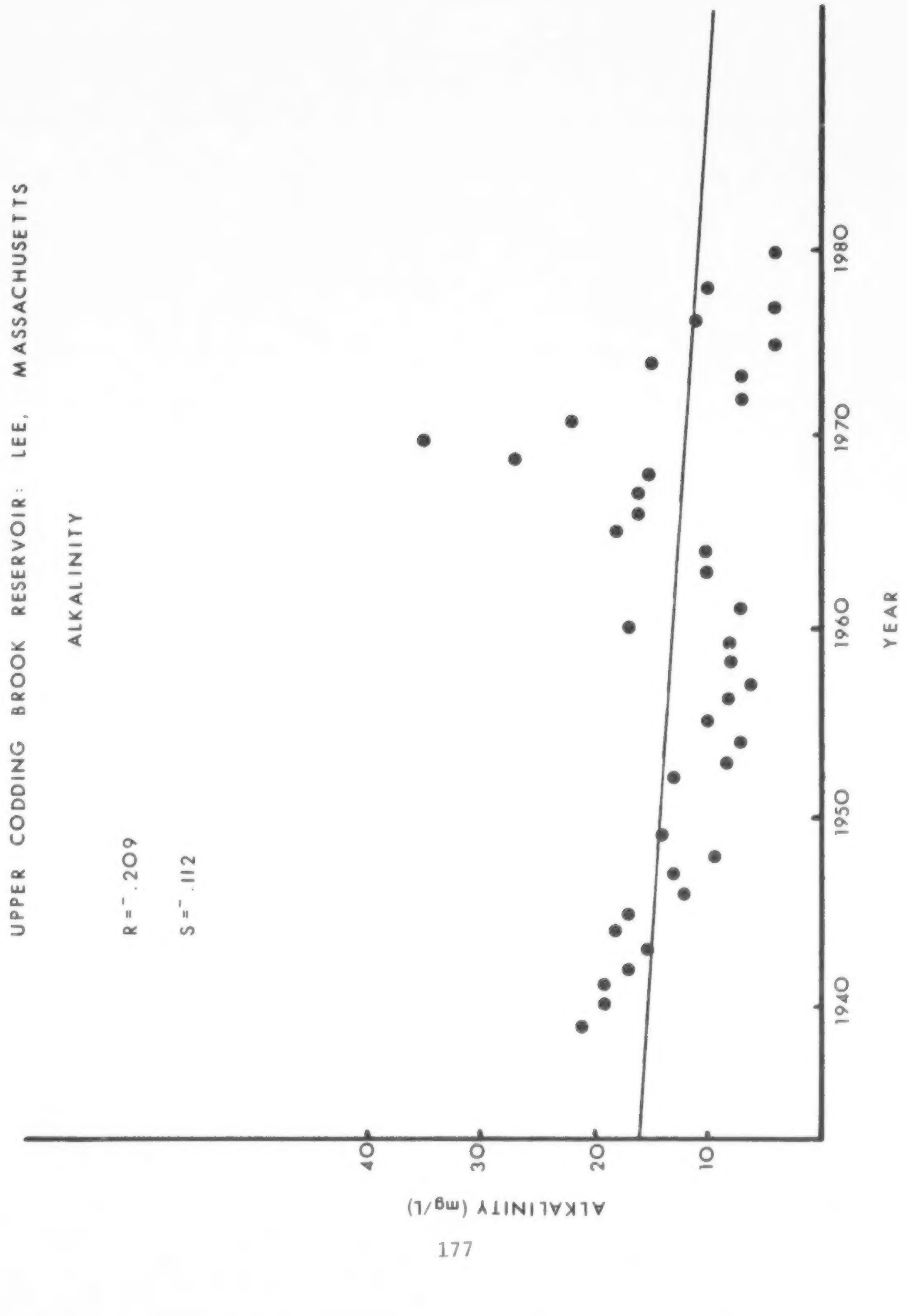




ROBERTS MEADOW BROOK: NORTHAMPTON, MASSACHUSETTS

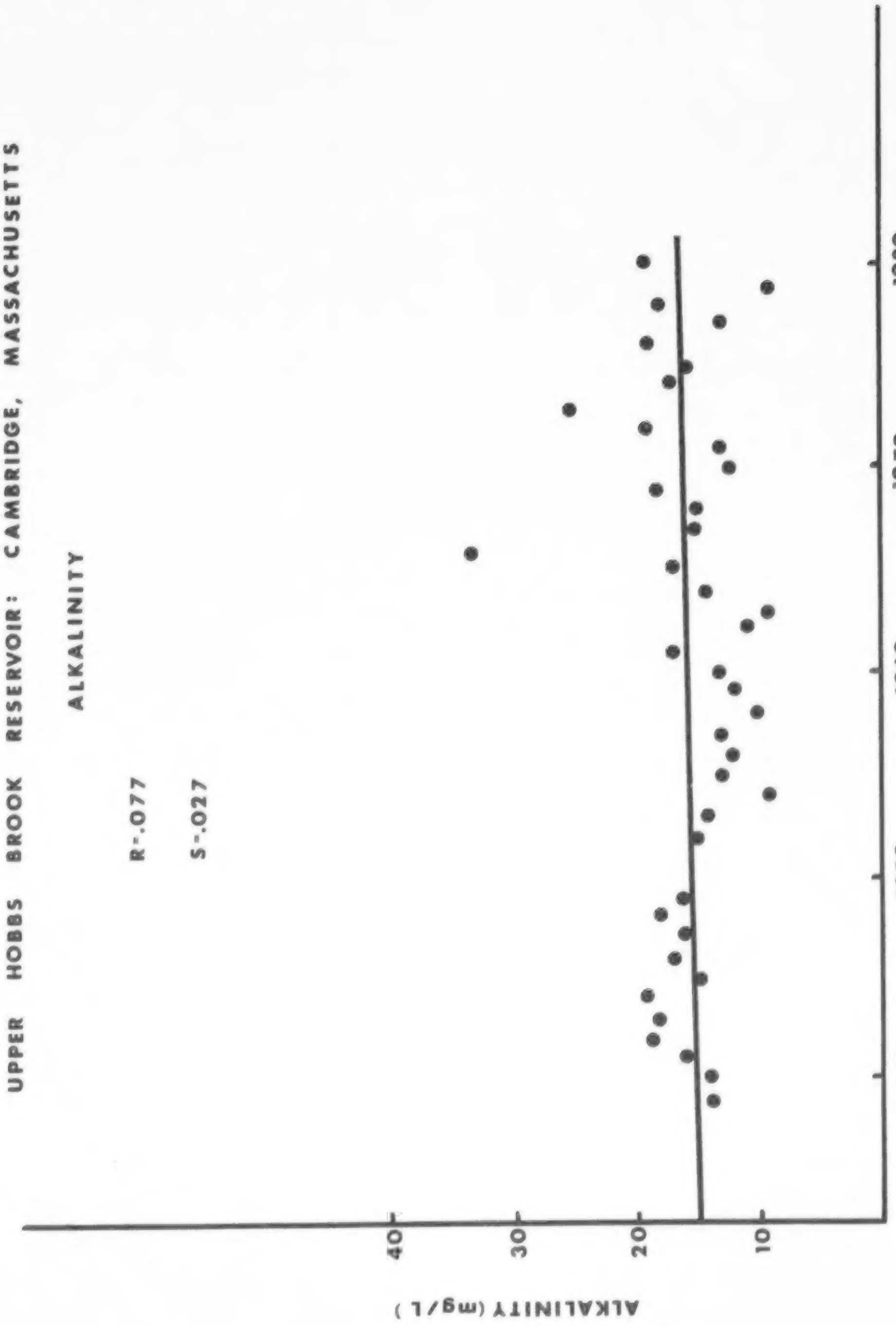
ALKALINITY

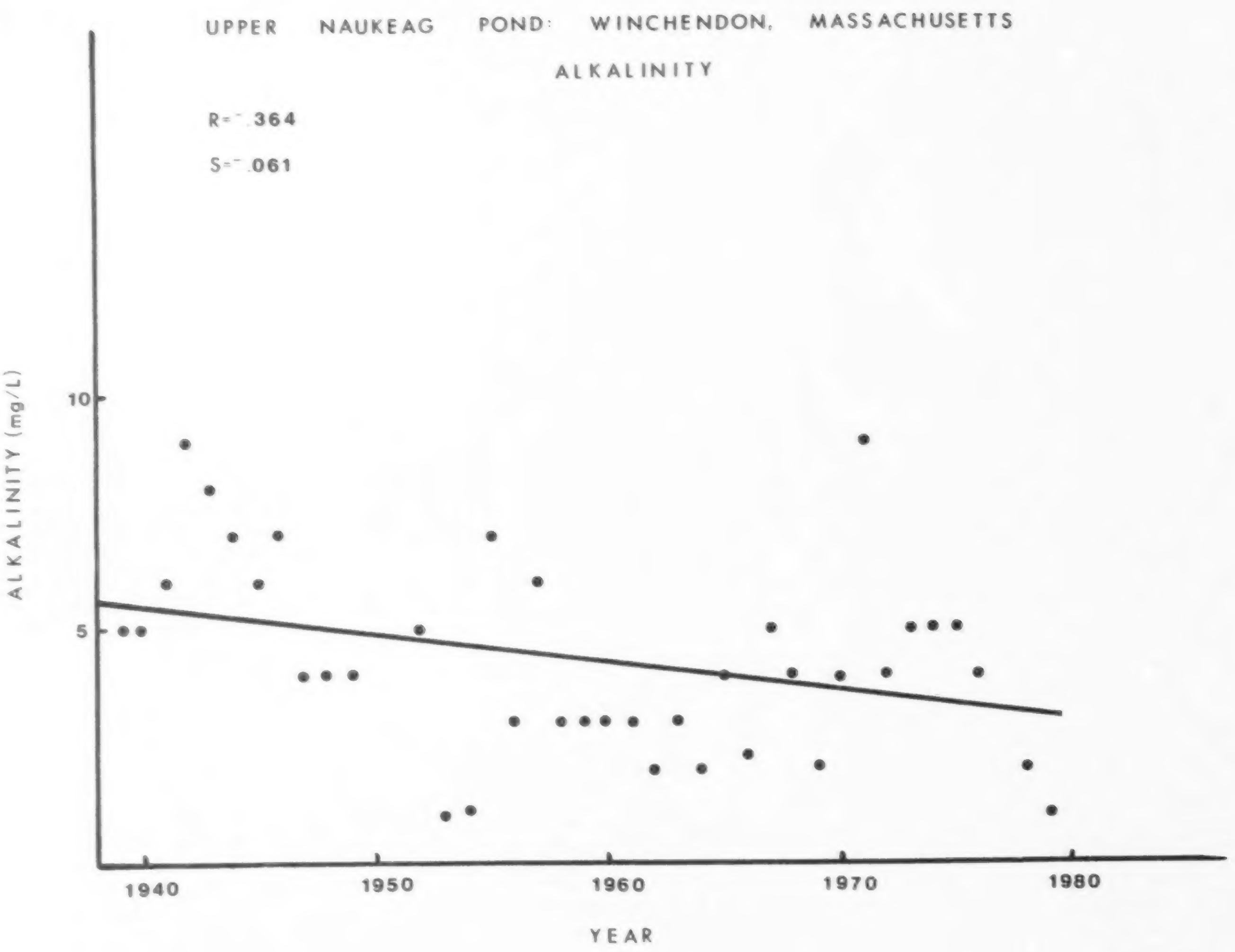

SHAW POND: SPENCER, MASSACHUSETTS
ALKALINITY
R=-.546
S=-.107
ALKALINITY (mg/L)
10
5
YEAR
1940
1950
1960
1970
1980



UPPER CODDING BROOK RESERVOIR: LEE, MASSACHUSETTS

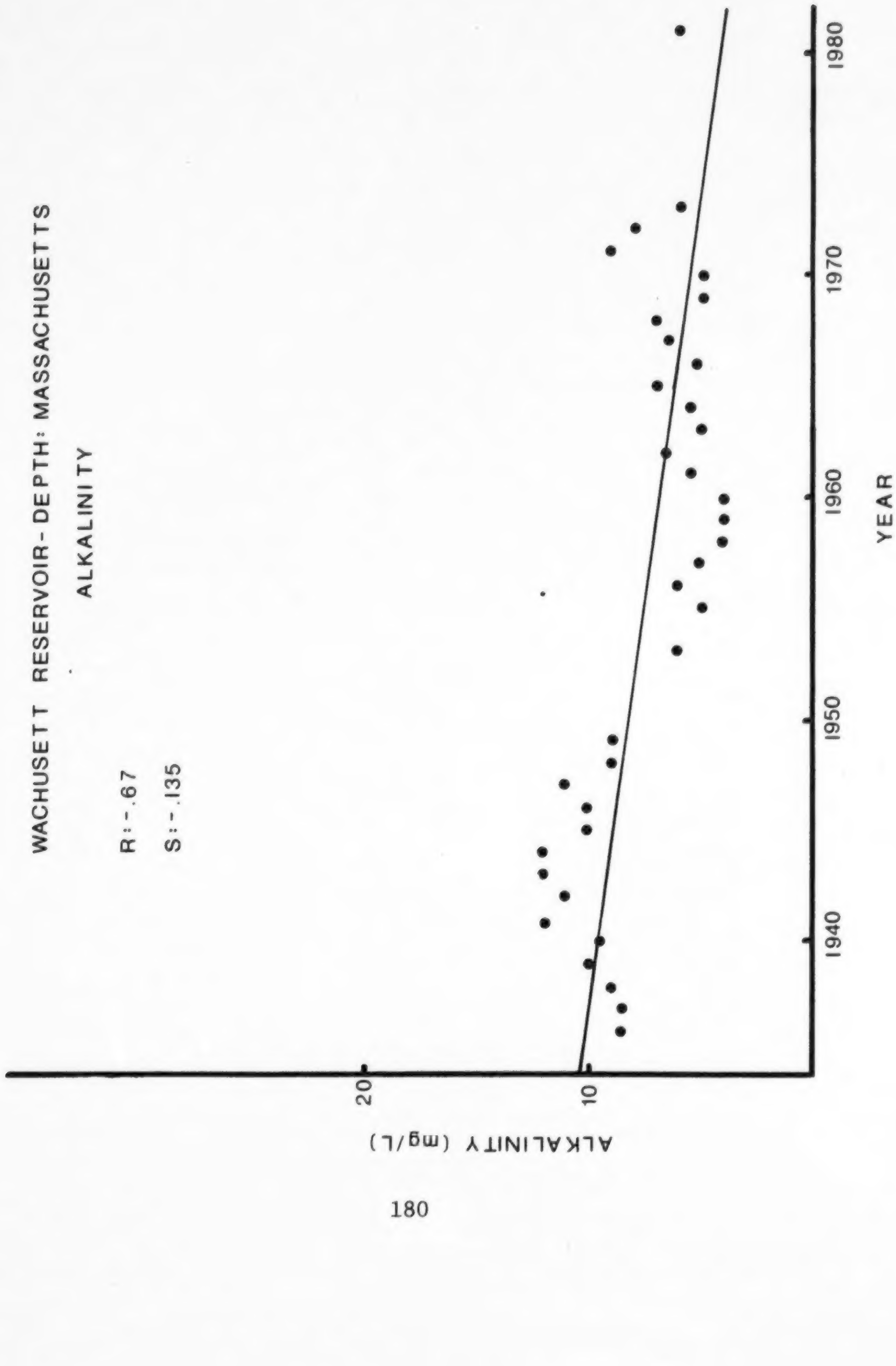
ALKALINITY

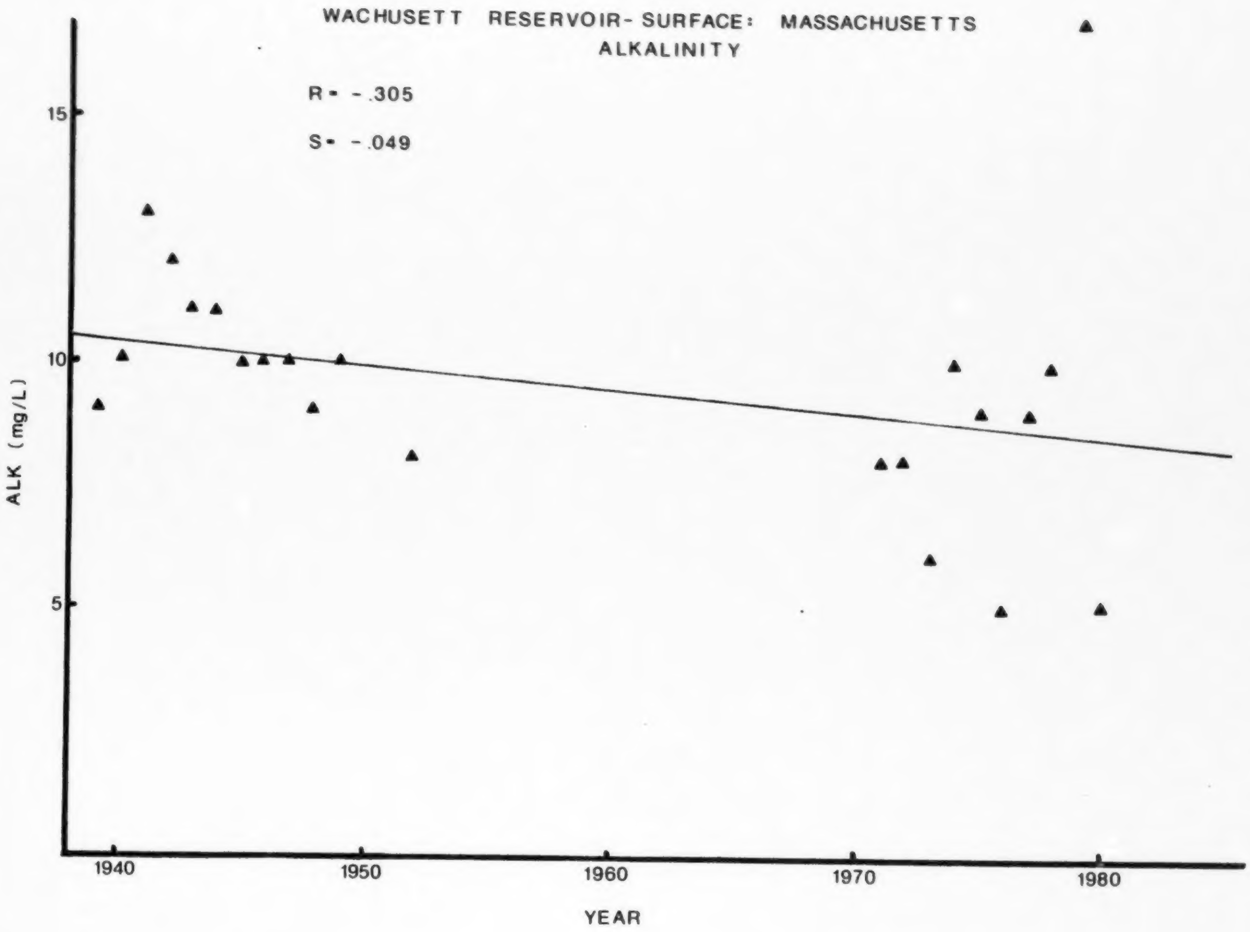

UPPER HOBBS BROOK RESERVOIR: CAMBRIDGE, MASSACHUSETTS
ALKALINITY
R=.077
S=.027
ALKALINITY (mg/L)
40
30
20
10
1940
1950
1960
1970
1980
YEAR

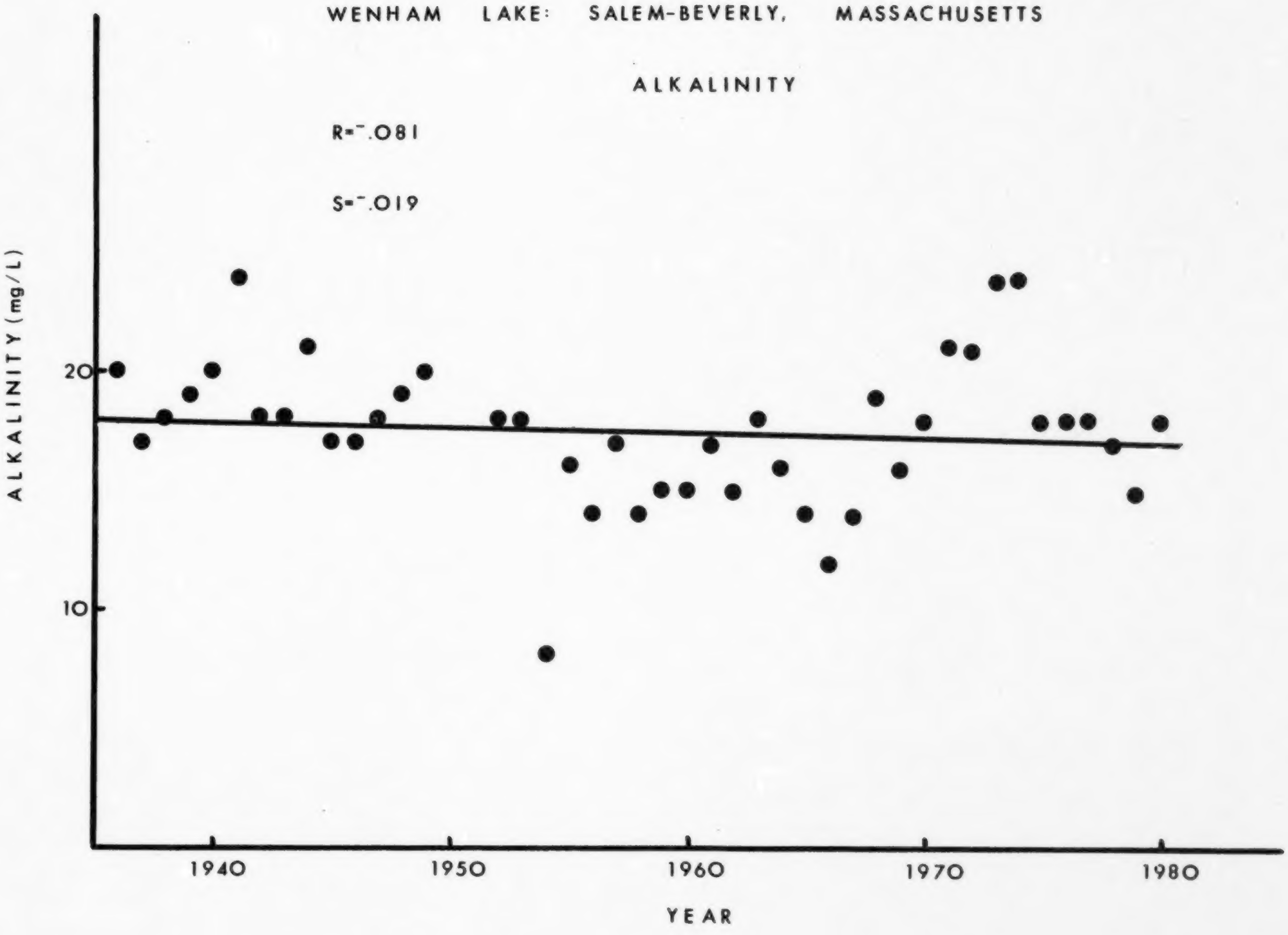


UPPER NAUKEAG POND: WINCHENDON, MASSACHUSETTS

ALKALINITY


WACHUSETT RESERVOIR- DEPTH: MASSACHUSETTS
ALKALINITY
R: -.67
S: -.135
20
10
ALKALINITY (mg/L)
1940
1950
1960
1970
1980
YEAR


WACHUSETT RESERVOIR-SURFACE: MASSACHUSETTS
ALKALINITY
R= -.305
S= -.049
15
10
5
ALK (mg/L)
1940
1950
1960
1970
1980
YEAR



WENHAM LAKE: SALEM-BEVERLY, MASSACHUSETTS

ALKALINITY